AD-A133442

REPORT OF THE MINE WARFARE STUDY GROUP (U)

Vol. VIII The SWATH as an MCM Platform

National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418
September 1982

Naval Studies Board

Commission on Physical Sciences, Mathematics, and Resources

UNCLASSIFIED

NRC:NSB:006

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THE SWATH AS AN MCM PLATFORM

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Commission on Physical Sciences,
Mathematics and Resources
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Work performed under Contract N00014-80-C-0160
with the Office of Naval Research

NATIONAL ACADEMY PRESS
Washington, D.C.

September 1982

"This work related to Department of Navy Contract N00014-80-C-0160 issued by the Office of Naval Research under Contract Authority NR 201-124. However, the content does not necessarily reflect the position or the policy of the Department of the Navy or the Government, and no official endorsement should be inferred."

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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The following group members contributed their personal time, expertise and, in some cases, discretionary funds to complete the analyses reported herein. Their contributions are gratefully acknowledged.

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TASKING

The Naval Studies Board of the National Research Council has recently completed a broad study of mine warfare under the auspices of the Mine Warfare Study Group. Recognizing the high cost of most minesweeping/hunting alternatives in relation to the perceived threat, the Study Group considered a number of low cost conceptual alternatives to the potential problem of inshore mining of U.S. boundary channels. One of these concepts, which was abandoned a number of years ago by the U.S. Navy, involves the use of small minehunting boats equipped with towed sonars and limited neutralization equipment. These units would be stationed at key ports for channel survey work in peacetime and minehunting during crisis or war. The most obvious limitation of this concept in the past has been the limited capability of small boats to operate in even moderate seas when towing sonar or sweep equipment. The old MSL open boat design displaced 11 t and was 36 ft in length, but was not capable of sustaining effective operations above Sea State 2 for any length of time. The MSL was also extremely crowded when outfitted for the mine countermeasures role. The 42 t MSB class, with a length of 57 ft, had adequate deck space but excessive motions in a seaway. However, in early 1981, construction work was completed in San Diego on the Small Waterplane Area Twin-Hull (SWATH) craft SUAVE LINO which displaces 41.5 t and was designed for private use. During the builders' trials the motions of the SUAVE LINO were found to be much lower than those of a conventional 42 t boat. Furthermore, the Naval Ocean Systems Center (NOSC) owns a 225 t SWATH boat, the SSP KAIMALINO, which has demonstrated exceptional seakeeping performance for almost ten years (see Appendix B). Other SWATH development activities around the world are summarized in Appendix C. The advent of the SWATH form thus provides new options for a small boat capable of stable towing operations in higher sea states.

In June 1981, a small Task Group was established by the Study Group to examine the applicability and comparative advantages of SWATH for the inshore mine countermeasures (MCM) role. This group met on several occasions during the second half of 1981 and early 1982 to discuss preliminary feasibility studies of SWATH boats in the 25 to 50 t displacement class. The results of these studies and the resulting recommendations are summarized in the next two sections.

The detailed tasking for this effort was as follows:

- Review small boat MCM concepts, including conventional small boats, in the context of the currently operational MH-53 helicopter towed systems to determine the feasibility and relative value of a SWATH alternative. Include consideration of mission equipment options and development requirements.

- Define conceptual characteristics for several SWATH boats which can meet informal mission requirements for the inshore channel survey and neutralization problem. Determine the smallest and lowest cost alternative that can meet the requirements.

- Consider safety, crew and logistical requirements and transportability options in defining the cost issues associated with the above alternatives.

- Consider the vehicle to be a dedicated Navy craft, possibly manned by Naval Reserve crews, in the comparisons.

- Consider existing military and commercial sonars as well as new design alternatives in sizing the mission payloads for the inshore MCM mission. However, the focus of the study is on the platform, not on mission sensor issues.

- Consider the missions of minehunting, including channel surveying as a precursor mission, and mine neutralization on a modular basis, as the primary mission for a small MCM craft. This emphasis excludes minesweeping as a major mission option and addresses modern mine targeting techniques against which direct minesweeping may be largely ineffective.

FINDINGS AND RECOMMENDATIONS

The conclusions of the group are summarized below. These are drawn from the discussions of the group and the technical data presented in the following sections of the report.

2.1 MISSION NEED

The SWATH Task Group reviewed the findings of the Mine Warfare Study Group regarding inshore mine countermeasures. Any further elaboration of mission need beyond their findings is outside the scope of this study. However, several factors are pertinent and relevant to mission need:

a. The current force of minesweeping helicopters is highly limited as to the number of channel clearing operations it can support during any given military conflict. The need for a rapid deployment MCM force supporting offensive operations is obvious and the current force appears well suited to this role given the anticipated introduction of towed minehunting sonars.

b. However, worldwide and persistent open ocean deployments of integrated Soviet naval forces are expanding in scope every year. If, through use of their second-line submarines, the Soviets could successfully circumvent U.S. ocean surveillance capabilities, CONUS ports along the East, Gulf and West Coasts would be vulnerable to mining. The real question is what number of mines the Soviets would consider necessary to effectively deter U.S. forces or shipping from port exit, and what lead time they could tolerate for the covert laying of these mines.

The SWATH Task Group is cognizant of the defensive mining orientation of the Soviet navy. However, considering the reported size of their mine inventory, the group is of the opinion that considerable resources in mines and delivery means exist to support an option for Soviet offensive mining by submarines of key U.S. exit lanes as a prelude to planned hostilities. This threat could encom-

pass all major U.S. port exit lanes, and would require a corresponding commitment of U.S. MCM resources at these locations to assure rapid detection and elimination of these mines. Clearing all these lanes in a timely schedule places a severe burden on present and planned MCM capabilities which, in an emergency, will be further stressed by priorities in widely dispersed geographical areas.

The preceding discussion assumes a mining effort by a major power against the United States. Another viable scenario is that a terrorist group or small nation might elect to covertly plant a few mines in one or more CONUS ports as an act of harassment or blackmail. The mines might well have been provided by a major power. The possibility of a "verbal" or "rumored" minefield should not be discounted. Such mining actions likely would not bring the United States to its knees but could be highly embarrassing if the United States is unable to take immediate and effective action.

2.2 MISSION PAYLOAD

The SWATH group examined the smallest feasible range of platforms for the channel survey and clearing mission subject to the requirements for operating in fully developed Sea State 3 and channel depths down to 200 ft. For some channels, such as those near Norfolk and Charleston, this depth requires operations out to 120 nmi from port. For these extended operations we considered offshore support for crews, fuel and spares such as a dedicated barge. This report does not consider the details of the operational procedures for SWATH MCM forces nor the support facilities required, but does recognize the importance of these aspects. With these mission objectives, mission equipment weight restrictions are significant. Consequently the Task Group looked at a range of equipment payload alternatives encompassing both existing and new design sonars, navigation and neutralization systems.

The minimum equipment characteristics needed to support channel surveying and minehunting/neutralization include the following:

TABLE 2.2

EQUIPMENT CHARACTERISTICS

Equipment	Performance Objective
Bottom Mapping Sonar:	
Towed Fish	Range: 75-100 yd (each side) Resolution: 3 in Speed: 6 kt
or	
Hull Mounted	Range: 100-150 yd Resolution: 3 in Speed: 6-12 kt
Obstacle Avoidance Sonar	Range: 300 yd View: 120° ahead
Navigation	Resolution: ±10 yd long term repeatable
Communications	Range: 200 nmi Type: HF/VHF telemetry
Mine Neutralization	Delivered charges by Manned Z-Bird boat or Remotely controlled vehicle

A survey of existing Navy and commercial sidelooking sonars indicated that none meets all of the requirements listed above. However, each has merit.

With these survey results the group concluded the following:

a. A hull mounted sidelooking sonar with variable focusing will eliminate a number of operational problems and will likely be feasible for a SWATH MCM ship given its excellent seakeeping stability. However, this sonar will require a new design using existing technology.

b. If a low cost sidelooking system option is preferred, the adaptation of a commercial sidelooking towed system is recommended to meet cost goals of $200,000 or less. In order to meet mine classification resolution requirements the aperture of a commercial sonar will have to be increased and its beam will have to be focused.

c. Options for a look-ahead, obstacle-avoidance sonar include both a variety of commercial (fishing) sonars or a militarized version such as the AN/WQS-1C system. This sonar needs to be mounted below the surface layer in areas of high near-surface temperature gradients. A pole-mounted sonar head would meet this need.

d. Several precision navigation options will likely exist by the mid-1980s. Starting in the mid-1980s, the ultimate in precision without external support can be obtained using the Global Positioning System (GPS) integrated with a small strap-down inertial system (INS) for short-term reference. An eight satellite or more constellation will be needed to achieve the required four-satellite continuous visibility. This deployment level is still pending approval in the Congress. However, if it is approved, commercial navigation options are now being developed which will provide less than 10-yd absolute positioning for less than $100,000 purchase cost, including an integrated strap-down INS.

   A lower performance, stand alone alternative is available on all CONUS littoral waters with Loran C. Loran C does not provide absolute ±10 yd accuracy, but does provide repeatable relative accuracy to nearly this precision when paired with a short-term strap-down INS. In addition, a number of line-of-sight cross-fix systems such as RAYDIST-T are available for inshore work should GPS not become available.

   The AN/SSN-2 integrated navigation system now available for Navy MCM operations weighs about 1.5 t when installed and is considered too large and costly by the Task Group for a small boat option. However, it appears several commercial navigation combinations exist in the 500 lb or less weight class.

The Task Group did not explore communications options in any detail. A number of low cost options appear to exist for HF/VHF telemetery over 150 nmi maximum ranges to port.

e. The overall conclusion of the Task Group is that lightweight mission equipment options exist in current technology for the minehunting/channel survey mission, and that the overall installed weight will be in the 3-5 t range including winches for a towed sidelooking sonar should that option be exercised. If a hull-mounted sidelooking sonar is developed for a SWATH, this weight estimate will be decreased. Mission payload costs are difficult to predict, but can fall in the $800,000 to $1.4 million range for the 33 t craft if commercial options are exercised.

f. Mine neutralization equipment options were briefly explored by the group, including both remote and diver delivered charges. These options included the French PAP-104, the U.S. Mine Neutralization Vehicle and various diver-delivered techniques. A remote vehicle delivery system for neutralization will add 4 to 10 t payload to the MCM small craft. Consequently, the Task Group recommends that only a limited neutralization capability be integrated with the minehunting payload. A Z-Bird boat delivery system with six spare charges requires only about 1.5 t payload.

Integrating a minehunting suite and a Z-Bird neutralization system results in a minimum payload range of 5-9 t for the total mission equipment suite (depending on choice of equipment).

Moored mines are not expected to pose a serious problem in shallow water. The vectored boat neutralization technique would not be effective against such mines, but shallow-water mechanical minesweeping (which could be done with a SWATH) would be effective.

g. The SWATH craft might well be suitable for use as the operating/control platform for the MK-18 system. Furthermore, it should be suitable for use as the control platform for a remotely controlled minehunting system.

2.3 SWATH MCM SMALL CRAFT FEASIBILITY

The Study Group asked for several independent, notional configurations of SWATH small craft in the 25-50 t displacement range. One study was made by the David Taylor Naval Ship Research and Development Center (DTNSRDC), SWATH Ship Development Office under Mr. Jerry Gore, and the other by the SSP KAIMALINO group under Mr. Dan Hightower at the Naval Ocean Systems Center (NOSC). In both cases, preliminary seakeeping motion spectra predictions were made using computer models at the Stevens Institute, Davidson Laboratory under Dr. Dan Savitsky's supervision. Dr. Savitsky also ran model tests of a monohull and catamaran form similar to the 36 ft MSL design for comparison with SWATH. The results of these very preliminary studies are provided in more detail in sections 4, 5 and 6.

In view of the many options for mission equipment summarized previously, no attempt was made to standardize on a specific payload configuration for these SWATH designs. Given the findings on equipment options, 3 to 9 t of payload was allowed for mission equipment. An additional 1.5 t was allowed for personnel and provisions, and 0.5 to 3 t allowance was provided for fuel, subject to various endurance objectives. Both studies included innovative propulsion and control systems for their concepts. DTNSRDC suggested a dual Harbor Master outdrive arrangement to be driven by medium speed diesel engines. The NOSC group investigated dual OMC long shaft outboard "Sea Drive" gasoline engines to provide an ultra lightweight drive system. These propulsion options are rated in the 350 to 450 hp range to provide 12 kt to 15 kt maximum transit speeds, depending on the specific displacement option.

Before continuing the discussion it should be noted that the Study Group clearly recognizes the well documented fact that gasoline at sea in a shock environment represents a hazard. However, we believe it worth noting that a properly designed SWATH would not represent the same risks as a monohull since fuel would be carried in the submerged hulls where it would be isolated from the manned areas. Fuel confined to the lower hulls would represent a relatively simple firefighting task using foam, CO_2 or Halon. Additionally, the fuel would be carried in rubber bladders housed inside the fuel/ballast tanks. The bladders would significantly reduce fuel spills due to shock. Fuel transfer lines would be shock resistant, and pass through areas (i.e., external to the struts) selected to minimize the buildup of explosive vapors in the event of rupture. In the final analysis, of course, the decision to adopt or

not adopt a gasoline-fueled power plant is a tradeoff between advantages and disadvantages such as that involving the Torpedo Boats of World War II.

The DTNSRDC configuration is a derivative of the recently constructed SUAVE LINO, a private SWATH craft displacing 42 t at launch, and currently modified to displace 49 t. The NOSC concept interpolates between SSP KAIMALINO (225 t displacement) and the 18 t displacement MARINE ACE existing SWATH hull forms. Both conceptual designs have aluminum hulls and superstructures to save weight. It is recognized that although aluminum is nonmagnetic, stray currents can be generated in any metallic hull which may create a magnetic signature of unwanted magnitude. It also should be noted that the explosion resistance of a SWATH type craft has not been evaluated. Neither have studies been made of the need for and effects on weight of special shock mitigating arrangements to protect equipment, machinery and crew. A start toward the accumulation of needed data to evaluate magnetic signature and explosion resistance characteristics of SWATH platforms could be made by obtaining the magnetic signature of SUAVE LINO and running explosive shock tests against SSP KAIMALINO.

The overall conclusion of the Task Group is that a new SWATH configuration, displacing 33 t to 54 t with full payload, is an excellent platform for inshore MCM work, and that a proper design, generally within the options range given below, will have relatively low risk in meeting cost and performance objectives. It is expected that SWATH hulls will be approximately 10-25 percent more costly than equivalent monohulls. More accurate cost data can only be obtained by preparing detailed designs and seeking the assistance of commercial and Navy cost estimators.

Table 2.3 summarizes the general characteristics of two representative configurations and their predicted motion responses. The characteristics of the MSB-5 Class are included for purposes of comparison.

2.4 STRUCTURAL INTEGRITY OF THE SWATH

The principal wave-induced loads which the cross-structure of a SWATH must withstand are transverse vertical bending moments. These bending moments are largest with the SWATH at rest in beam waves whose lengths are 3 to 4 times longer than the transverse spacing between the two hulls. Thus, for the conceptual SWATH craft in this study, wave lengths between 100 and 150 ft develop maximum

TABLE 2.3

GENERAL CHARACTERISTICS AND PREDICTED MOTION RESPONSES OF TWO SWATH CONFIGURATIONS COMPARED WITH THOSE OF THE MSB-5 CLASS

	NOSC (A) (Twin Struts/Side)	DTNSRDC (B) (Single Strut/Side)	MSB-5 Class
Weight & Displacement, Long Tons			
Ship Structure	18.2	27.0	11.96
Propulsion	1.5	7.0	{14.69}
Electric Plant	0.6	{6.5}	
Aux, Comms, Outfit	1.5		2.64
Margin & Soakage	4.4		1.28
Light Ship Displacement	26.2	40.5	30.57
Fuel	1.3	3.0	4.80
Personnel & Provisions	0.6	1.5	.88
Mission Payload	5.0	9.0	4.85
Design Load Displacement	33.1	54.0	41.10
Dimensions			
Length*	42.0 ft	61.5 ft	57.25 ft
Beam	32.1	30.3	15.83
Draft	7.1	5.0	4.33
Freeboard (AWL)	6.0	5.5	3.64
Deck Clearance	4.0	4.0	NA
Propulsion			
Drive	OMC Outboard	6-71 Detroit Diesel	Packard Model 20-850
Engines	Two at 235/470	Two at 175/350	Two at 600/1200
Speed (MAX)	15 kt	12 kt	12 kt
Endurance & Speed	100 nmi at 15 kt 18 hr on station at 6 kt	300 nmi at 11 kt	358 nmi at 12 kt

*Submerged length for SWATH

TABLE 2.3 (Continued)

Seakeeping	NOSC (A) (See Note 2)		DTNSRDC (B) (See Note 2)	MSB-5 Class (See Note 1)
	5 ft Significant Wave Height (SS-4)			
	6 kts	15 kts	6 kts	0 kt-3.5 ft Sig. Head and Beam Sea
Pitch	1.8°	2.1°	2.1°	5.1°/--
Roll	1.9°	3.1°	1.7°	--/10.1°
Heave at LCG	2.2 ft	2.2 ft	2.4 ft	3.4 ft/6.7 ft
Vertical Acceleration at LCG	0.04 g	0.04 g	0.04 g	--
MSI (2 hr Motion Sickness Index)	1%	2%	1%	--
	10 ft Significant Wave Height (SS-5)			
Pitch	3.2°	3.6°	3.5°	
Roll	3.2°	5.2°	2.9°	
Heave at LCG	4.6 ft	4.5 ft	4.9 ft	
Vertical Acceleration at LCG	0.07 g	0.08 g	0.08 g	
MSI (2 hr Motion Sickness Index)	3%	6%	4%	

NOTES:

1. Not available at comparable speeds or sea states. Data presented is estimated from 33 and 53 t data from Table 6.1, page 62.

2. Suitably weighted average values for all headings and Ochi's mean North Atlantic two-parameters wave spectrum family. (SNAME Transactions 1972)

bending moments which are readily calculated by existing validated analytical techniques or obtained from model tests. Typically, the wave length of maximum energy in Sea State 5 or higher is substantially greater than 150 ft, which means that the bending moments experienced by these conceptual SWATH craft in severe seas would not be significantly higher than in state 4 seas.

The vertical bending moments on the cross-structure can be substantially reduced by changing heading away from the beam sea direction.

The underside and frontal areas of the cross-structure must withstand slamming pressures--especially in head seas. These pressures increase with sea state and speed and can be easily measured in a model test.

Design procedures exist to confidently select adequate scantlings and bottom platings to accommodate these slamming pressures. As with conventional displacement ships, the frequency of slamming and the magnitude of impact pressures can be reduced by decreasing the speed of the craft.

A further discussion of the structural integrity of SWATH is contained in Appendix A.

2.5 FINDINGS AND RECOMMENDATIONS

With these summary feasibility data the Task Group agreed on the following findings and recommendations:

The following are among the Task Group's findings: (1)

a. A SWATH hull form displacing 33 to 54 t appears to have excellent seaworthiness characteristics for the inshore MCM mission while housing ample payload for minehunting with limited neutralization. The open deck space of the SWATH option is large compared to other hull types and a center-well option is available if a towed sidelooking sonar is required. The high freeboard reduces deck wetness problems.

(2)

b. The seakeeping characteristics predicted for the SWATH hull form will permit a hull mounted sidelooking sonar option with minimum yaw compensation and no roll and pitch compensation. For channel surveys at water depths down to 100 ft, survey and mine classification appear feasible in the 100 to 200 yd sidelooking range interval. A towed fish could then be used for

deeper channel segments. The advantages of a hull mounted system look significant and the group recommends this option be explored further should the Navy decide to build small SWATHs for inshore MCM work.

cont fr p12

(3)

c. The results of computer predictions of the motions of the two proposed SWATH designs show that, when suitably averaged for all headings, and when operating at 6 kt in a state 3 sea ($H_{1/3}$ = 5.0 ft), the roll angle amplitude for all designs will be less than 2°; the heave amplitude at the LCG will be approximately 2 ft; and the LCG accelerations approximately 0.04 g. These small motions and accelerations provide a comfortable working environment for crew and instrumentation. and (4)

d. The comparative seaworthiness of a monohull, ASR Catamaran form, and MCM SWATH in the same environment are presented in Table 6.1 for displacements of 33 and 53 long tons. The SWATH data were obtained from computer programs at Davidson Laboratory, Stevens Institute of Technology. The monohull data were obtained from a brief series of model tests of a 36 ft MSL-like monohull in head and beam seas and the results extrapolated to the 33 and 54 long ton SWATH sizes. The catamaran results were obtained using motion and acceleration response operators taken from Pritchett's* and Wahab's** studies of ASR catamaran forms and applied to 33 and 54 long ton sizes.

In summary, the motions and accelerations of the SWATH hulls were substantially less than those for monohull and catamaran. Specifically, for a Pierson-Moskowitz sea spectra with $H_{1/3}$ = 4.0 ft the estimated peak roll amplitude of the SWATH was only 6.3° while, in the same sea state, the monohull form is expected to roll 21.8° and the catamaran 18.1°. In head seas, the peak pitch

*Pritchett, Clark, "Model Studies of Ship Motions of ASR-Catamaran," DTNSRDC, T&E Report No. 340-H-02, January 1970.

**Wahab, Rama; Pritchett, Clark; Ruth, Lawrence C., "On the Behavior of the ASR Catamaran in Waves," Marine Technology, Vol. 8, No. 3, July 1971.

angle of the SWATH is 4.0° while for the monohull it is 6.6° and for the catamaran, is expected to attain a value of 12.1°--approximately three times larger than the SWATH form.

This brief comparison demonstrates the superior seaworthiness and, hence, the safer and more comfortable working environment for a SWATH relative to an equivalent monohull or catamaran hull in this size of vessel. These same characteristics allow operations to continue into higher sea states.

e. Both the NOSC and DTNSRDC feasibility studies suggested innovative propulsion options to facilitate maintenance, and in the case of the OMC drive, to reduce weight. The outboard drive options look very attractive for precise track control in the low speed MCM mission and appear uniquely suited to the SWATH hull form in this size class. If an outboard gasoline engine option (OMC Sea Drive) is acceptable to the Navy, the weight savings will be significant compared to a medium speed diesel engine option, but will be much less significant if compared to a high speed diesel option.

f. A SWATH in this tonnage range involves few risks or unknowns. Both studies are extrapolated from existing SWATH hull forms using aluminum as the primary structural material. Additional options may exist for GRP and Kevlar which should have lower magnetic signature characteristics, and which may also result in a lower cost. But there are developmental risks to be resolved in fabricating and fastening the major structural elements to withstand the arduous service and loads required of the vessel. Consideration of shock loads and safety features was not within the scope of this study.

Preliminary cost estimates made by the NOSC team put the production costs for the SWATH without its mission equipment in the $300,000 to $500,000 range provided that a number of them are built and that commercial practices and standards are used. Independent cost checks by the DTNSRDC staff with the builder of several Japanese SWATHs, Mitsui Engineering

and Shipbuilding, indicated that their experience leads them to conclude that a SWATH will cost about 10 percent more than a monohull designed for the same payload, speed and endurance, and using comparable materials, outfit and standards.

In summary, the group concluded that SWATH acquisition costs should be reasonably predictable for craft in the proposed displacement range, and that aluminum, GRP and Kevlar hull structure options should be explored in detail on a comparative basis. The total cost of the craft appears to fall in the same range as the total for the mission equipment. Hence, a total mission equipped unit should fall in the $0.8-1.4 million range for the 33 t craft if a production buy can be made and commercial standards accepted.

3.

POTENTIAL MCM EQUIPMENT FOR SWATH MCM CRAFT

This section describes MCM equipment suites which might be installed on a small MCM SWATH craft. Data are presented on weights, dimensions and tow tensions where applicable. Some data are firm while others are estimated. Some of the equipments are in existence, some are under development and some would require development. Emphasis is on the minehunting role. The small SWATH craft probably will not be well suited for minesweeping. It would seem that less specialized craft-of-opportunity could perform mechanical and influence (magnetic and acoustic) sweeping as well as the SWATH, and at lower platform costs.

3.1 CHANNEL SURVEY (BOTTOM MAPPING) MISSION

This is both a peacetime and wartime mission and in some ways is the least demanding of several potential tasks, but is a very important and useful one. For this role the SWATH carries a sonar (likely a sidelooking type), either towed or hull mounted, to map the floor of the inshore ship channels and harbors. The peacetime role is to determine the bottom type and relief, plot bottom contacts, determine the density of mine-like bottom objects, provide data for channel selection and to practice the detection, localization and classification of simulated mines. It does not specifically involve the destruction or removal of mines. The wartime role is to determine if mines are present and, if so, where (mine avoidance is an excellent countermeasure). Other MCM systems would then concentrate on those areas for mine clearance. Operating in a mined area is a dangerous activity since the SWATH may travel over or near mines. However, it is expected that the signatures of the SWATH will be no larger than those of a conventional craft of the same size. The offensive miner is not likely to target his mines against such small craft, provided that the craft is of low cost. The defensive field probably will include anti-sweeper mines. For this mission the MCM task is that of minehunting and the basic system is composed of: (1) the SWATH platform, (2) a bottom mapping sonar, (3) a precise navigation and plotting system, and (4) a small aheadlooking sonar for obstacle avoidance and to cover to some extent the holiday in the search pattern of the sidelooking sonar directly beneath the SWATH. It is assumed that bottom mapping will be carried out in water depths no greater than about 100 m (perhaps only 50 m) since current bottom mines are relatively

ineffective against surface targets in water depths greater than about 60 m.

3.1.1 Potential Bottom Mapping Sonar

C-MK-1 Shadowgraph Sonar

This is a towed sidelooking, very high resolution sonar which is approved for fleet use and a few sets (perhaps 10 to 20) exist. It is towed 15 ft above the bottom (automatic bottom following) at a speed of 4-6 kt. There are two sonars in each towed body, each sonar having a range of about 80 ft. A single towed fish system has a total searched path of about 50 yd while the two-fish configuration has a searched path of about 100 yd. This sonar has a range and cross range resolution of about 3 in, which is as good as any available sonar, and is much better than most. It is an excellent bottom mapping sonar and it is available. A weak point is its age (it was designed in the late 1950s and produced in the early 1960s). It is difficult to maintain. The range is less than desired.

Single Fish Configuration

Console	52.5" high x 33" wide x 32.5" deep	650 lb
Vehicle	24.3" high x 788" wide x 106" deep	400 lb
Cable/Reel	600' of cable, 44" d x 23"	550 lb

The weight of a single fish system is about 1600 lb total, plus the weight of the handling equipment (small crane), operating hut and primary power plant. A two-fish system would have slightly more than twice the weight and volume due to the requirement for diverters.

The fish is normally towed about 300 ft astern. The estimated towing tension per fish when operating at 100 ft depth is 300 lb at 6 kt.

DUBM-41B (built by Thompson-CSF in France)

This is a two towed body system which is very similar to the C-MK-1 described above except that it operates at about 650 kHz, which is about half that of the C-MK-1, and it has the potential of somewhat longer ranges (with

poorer resolution). It is a modern, well engineered sonar. The cost (1980) was Fr 2.5 million ($650,000).

Weights and Dimensions

	Height	Width	Depth	Weight
Console (Double Unit)	1.98 m	0.6 m	1.22 m	460 kg
Magnetic Recorder	0.67 m	0.48 m	0.4 m	?
Paper Recorder	0.19 m	0.32 m	0.55 m	?
Towed Body (Each)	0.36 m	0.721 m	3.724 m	340 kg
Cable and Winch			?	?

Estimated towing tension of 500 lb for a two-fish.

This sonar is configured only as a two-fish system. Its total weight and volume is intermediate between the one and two-fish C-MK-1 systems.

This is an excellent modern sonar but it is moderately expensive and is of foreign manufacture.

AN/AQS-14

This is a modern sidelooking sonar which has been developed for use with helicopters for minehunting. Due to the unclassified nature of this report we will not discuss it further here except to say that it should be considered for application to a SWATH MCM boat.

Commercial Sidelooking Sonars

There are a number of bottom mapping sidelooking sonars available which are intended primarily for the civilian market but which may have naval applications as well. These are typically of modern design, well engineered and much smaller in size and weight than the military systems. If the SWATH is designed to handle the C-MK-1 or the DUBM-41B, it should be able to handle any of the civilian sonars with ease. The costs of these sonars are typically less than Navy systems. In general, these sonars do not have the high resolution in cross range found

in the Navy sonars (they are not focused) and one would not expect them to be very effective in mine classification, but they could be useful in peacetime channel mapping and in channel selection. All of the systems are towed single fish systems.

a. Klein. Frequency ranges from 100 to 500 kHz, depending on model. The towed body (typically) is 48 in long, 3.5 in d (12 in tail d) and weighs 48 lb in air. The lateral range is 25-100 m. Maximum towing speed is 16 kt. For the 500 kHz model, the horizontal beamwidth is 0.2°, but this is farfield. It is not focused so the actual cross-range resolution at the ranges of interest will be about that of the aperture. The display is paper tape recorder. One can purchase a combined side-looking sonar and 3.5 kHz sub-bottom profiler (which can be useful in estimating bottom composition). The cost ranges from $50,000 to $100,000, depending on features, etc. Altitude above bottom is controlled by cable payout (and speed). The cable diameter is 3/8 in. The display console is 10 x 33 x 24 in and weighs about 100 lb.

b. EG&G Model 960 Sea Floor Mapping System. This is a modern sidelooking sonar which operates at 59 kHz and can be towed at depths to 18,000 ft. It has ranges from 300 to 1500 ft. The Model 990 tow fish is 65 in long x 10 in d (fins 24 in) and has an air weight of 200 lb. The tow cable is 0.324 in d and weighs 0.178 lb/ft in air. Tow tension at 6 kt and 1500 ft depth is 800 kg. The operating console (display, recorder, etc.) is 20 x 10 x 18 in and weighs 65 lb. Total power is about 100 W.

c. Other civilian sidelooking sonars are made by: EDO Western, Ocean Research Equipment, UDI and perhaps others, but they do not differ greatly from the Klein or EG&G systems.

Recently, NCSC has made comparative tests on four commercial sidelooking sonar in a minefield which had previously been mapped with both the C-MK-land the AN/AQS-14. The results are not yet available, but should be extremely interesting and useful.

New Design Towed Sidelooking Sonar

None of the sidelooking sonars which now exist or are under development appear to be ideal for the intended application in terms of cross-range resolution, maximum range and speed of advance (without holidays). A good compromise sidelooking sonar might have a range and cross-range resolution of 3.0 in with a maximum useful range of 100 yd (200 yd path), at a speed of 6 kt (preferably higher--perhaps 12 kt). The receiving array would need to have either range or time-varied focusing. For an operating frequency of 500 kHz ($\lambda = 0.12$ in), the focused beamwidth would need to be about 0.05°. This would require a basic aperture of 1000 λ, or 10 ft. This would have to be increased to permit high attenuation of minor lobes (shading) and to allow for multiple parallel receiving beams. On this latter point, at 6 kt, for 100 yd maximum range, it would be necessary to have five parallel beams to each side in order not to have holidays. This would increase the length of the array by 1.25 ft. These may not be the best set of parameters but in general it would appear that this type of sidelooking sonar would require a towed body about 15 ft in length.

From the standpoint of using such a sonar on the SWATH, the total weight of the system should not exceed that of the two-fish C-MK-1 and perhaps might be as low as the one fish system. The towing tension should not be any greater than that of the single fish C-MK-1 system.

It should be noted that this type of very high resolution sidelooking sonar should have naval applications other than for SWATH. These include Naval Oceanographic Office (NAVOCEANO) channel surveys, Swimmer Delivery Vehicles (SDV), Airborne Mine Countermeasures (AMCM) and MCM craft of opportunity.

New Design Very High Resolution Hull Mounted Sidelooking Sonar

The SWATH type of MCM platform offers an excellent opportunity to experiment with a very long aperture sidelooking sonar by mounting the array on the underwater hulls of the SWATH. Such a configuration has the disadvantage of not providing for the best geometry for bottom mapping at all water depths of interest (e.g., the deeper waters) but it has several very important advantages such as the following:

a. The launch and recovery problems will be eliminated.

b. A long aperture can be employed.

c. The costs of the towed body and handling gear are eliminated.

d. The system is "deployed" at all times and, hence, likely will be used routinely--not just for special missions.

e. The SWATH can be stopped or maneuvered to investigate targets of special interest, without concern for a towed array. This is very important for a total mine clearance concept.

f. Even with a larger aperture, the total weight of the system should be less than that of a towed body system with a much smaller aperture (because of no towed body, cable or handling gear). The location of the arrays tends to lower the center of gravity of the system.

These potential advantages make a compelling case for using a long aperture hull mounted sonar on SWATH. Assume that one desires very high target classification capability at lateral ranges of $\pm$100 yd and good (but slightly degraded) performance at ranges of $\pm$200 yd. For several reasons we choose a frequency of about 300 kHz ($\lambda = 0.2$ in). For a cross range resolution of 3.0 in at 100 yd and 6 in at 200 yd, a basic unshaded single beam aperture of about 17 ft would be required. As before, for multiple parallel beams and for minor lobe reduction, the aperture might be as much as 20 ft. Because of the slower pulse rate needed for 200 yd range (4 per sec), for a speed of 6 kt, it would be necessary to have ten parallel beams to each side. This would increase the aperture by 2.5 ft. One probably would want to install one transducer array on the inboard side of each hull (looking beneath the opposite hull) in order to minimize the width of any holiday beneath the platform. The sonar beams would have to be focused at all ranges of interest. This might be a time-varied focus (objects on the bottom and in the volume would all be in focus) or a geometrical focus along the bottom (only bottom objects would be in focus). For the latter, the focus would have to be adjusted for each water depth.

It should be noted that it may be feasible to operate a sidelooking sonar in a very short scope, towed configuration. In this concept the tow cable is heavily weighed near the point of attachment to the towed fish, such that the tow cable is nearly vertical in the water.

Basically, this is the same scheme as used on the AN/SQQ-14 and AN/SQQ-16 aheadlooking sonars. If the tow point is near the bow of the towing platform, the fish can be made to tow virtually beneath the platform for the speeds and water depths of primary interest in this application. Preliminary designs indicate that the concept is feasible. We understand that some of the civilian sidelooking sonar are sometimes operated in this manner. The merit of this configuration is that the SWATH can stop or slow when a contact is detected and classified, and immediately initiate neutralization action without concern about the side-looking sonar trailing a long distance behind. The target of interest will be approximately abeam of the platform and within range of the aheadlooking sonar. In this configuration the sonar fish could be towed at the optimal altitude above the bottom.

3.1.2 Obstacle Avoidance Sonar

It would be useful to have a small, hull-mounted aheadlooking sonar for obstacle avoidance and to compensate to some extent for the distorted coverage by the primary sidelooking sonar in the bottom area directly beneath the SWATH. This sonar also can be used for other purposes such as vectoring divers to targets of interest (not a part of the primary bottom-mapping mission).

Several small, aheadlooking sonars are available on the civilian market. Probably the best choice among the relatively small and inexpensive sonars is the AN/WQS-1 which is the same as the Ametek Straza Model 300. The cost of this sonar is about $35,000. It is electronically scanned over the forward 120° (this sector can be rotated) using 40 preformed 3.0° beams. Range is a function of target but may be up to 500 yd. The weight of the underwater portion is 44 lb (in air), the display is 22 lb, for a total weight of well less than 100 lb. Power consumption is about 60 W. The sonar could be mounted either on a pipe column or in the bow of one of the underwater hulls.

3.2 MINEHUNTING (INCLUDING MINE CLEARANCE)

This mission involves search, detection, localization and classification of mines with subsequent destruction or removal of mines found. Two generic types of systems designed to carry out this mission potentially using a small SWATH platform are described.

3.2.1 Aheadlooking Sonar System

This is the basic type of system used by the United States (MSO), United Kingdom, France, Italy and West Germany. A high resolution sonar searches a sector ahead of the platform (ship) and detects mines at the range of perhaps 300 yd (at lateral ranges of perhaps ±150 yd). At ranges of about 100-150 yd, the targets are classified as mine or non-mine. If the former, the platform hovers and the sonar is employed to vector either a manned or remotely-controlled rubber boat to the near vicinity of the target where a neutralization charge is deposited close to the mine for subsequent detonation. After this, the search proceeds to the next target of interest.

The U.S. Navy employs the AN/SQQ-14 variable depth sonar; the United Kingdom employs the ASDIC-193M; France, Netherlands and Belgium use the DUBM-21-B; West Germany has the DSQX-11H under development; while Italy uses the AN/SQQ-14. All of these sonars are large, heavy and expensive. The AN/SQQ-14 has a total weight of about 10,000 lb, occupies several large cabinets and has a massive hoist and towed body. Power required is about 10 kW. The ASDIC-193M weighs about 6000 lb. It is hull mounted and much of the weight (and cost) is in the stabilized sonar array platform. This stabilized platform system might not be required on a SWATH platform. The DUBM-21B has a sonar weight of about 4500 lb plus the stabilized platform weight of about 10 t. As with the ASDIC-193M, the stabilization system might not be required. The DSQX-11H has a total weight of about 5700 lb. None of these sonars seem to be well suited for use on a small craft even if extensive modifications were made.

The AN/SQQ-16 is a variable depth (VDS) mine detection and classification sonar which was designed for use on small MCM craft such as the MSB and MSL. It is a very old sonar (preliminary design in 1958 and built in the mid-1960s), and only two were built. One is now installed on the MSB-29 at Charleston and is having considerable success. We can use it to estimate the size and weight of a suitable sonar which could be built for use on small craft.

Total power consumption for the sonar is 1.0 kW plus 4 kW for the hoist (when in operation). This indicates that a suitable sonar system could be built for this mission with a gross (air) weight of 4000 lb or less, exclusive of sonar hut and primary power generator. The vertical cable tension is 1200 lb with a horizontal (towing) tension of 400 lb at 6 kt.

Unit	Size	Weight
Operators Console	68" (h) x 29 x 19	650 lb
Towed Body	36" diameter	1200 lb
Tow Cable and Fairing	75' long	450 lb
Hoist and Controller		1450 lb
Sonar Hut, Air Conditioner and Motor Generator	76" x 96" x 48"	1050 lb
	Total weight	4800 lb

For neutralization, the United States depends on using a manned Z-Bird rubber boat to transport the charge to the mine. The boat is 15 ft long, about 5 ft wide and weighs 150 lb without engines. It is powered by a 35 hp outboard motor. The air weight of the neutralization charge is 368 lb, which includes 212 lb of explosive.

France, Belgium, Netherlands, United Kingdom and West Germany all use the (French) PAP-104 wire guided submersible to deliver a 309 lb neutralization charge (220 lb of explosive) to the mine. The PAP-104 can operate to depths of about 100 m at speeds up to 5 kt. It has a length of 2.7 m, width of 1.2 m, height of 1.3 m and in-air weight of 1543 lb with charge. The battery pack can operate about 100 min and requires 2 hr for recharge. The battery is 32 V and 145 a-h. The usual PAP-104 system includes two vehicles and a small control console (with closed circuit TV display). The 1980 cost was about Fr 1.7 million (two vehicles plus console).

In a peacetime operation, the SWATH need not carry neutralization gear but will need to carry (or tow) a small rubber boat for divers to use in inspecting targets, i.e., obtaining "ground truth" target identification. In time of war or crises, if mines are found, it will be essential to recover some of them for intelligence purposes. This is a job for the EOD teams. Such teams are not likely to be assigned routinely to each MCM unit, but they could be transported to the mined area very quickly. The task of the MCM unit would be to have the mines located and probably marked with buoys.

Subsequent clearance of the minefield would either be done by sweeping (mechanical--including bottom trawls--and/or influence) or by using the SWATH minehunter in a

target-by-target neutralization operation. The least complex way to do the latter would be to use the aheadlooking sonar to vector the rubber boat with an explosive charge to the mine. At present these boats are manned, but the feasibility of using radio or wire control was demonstrated by both the United Kingdom and the United States some 20 years ago. It should be noted that a SWATH would not need to carry a large stock of neutralization charges. They could be replaced by another vehicle as the charges are consumed. Furthermore, if divers are used to emplace neutralization charges, the size of the charge need be only a few pounds instead of 300 lb.

The point of this discussion is to indicate that there are potential ways to effect appropriate neutralization without requiring massive equipment. The size and weight of the neutralization equipment should not be a controlling factor in determining the size and displacement of the SWATH craft.

The neutralization systems considered herein have emphasized attacking bottom mines since this type is a more likely candidate to be laid covertly by submarines. Moored mines could be swept by other craft using standard mechanical sweep.

3.2.2 Sidelooking Sonar Systems

In the past, most sidelooking sonars have been installed in towed vehicles. This configuration is excellent for bottom mapping but does not lend itself well to a "stop and go" or "blow as you go" mine clearance operation. Several attempts in the past to develop equipment and procedures for neutralizing mines "on the run" (i.e., without slowing down or stopping) have not been successful. The SWATH platform equipped with <u>very</u> high resolution hull-mounted sidelooking sonar offers an opportunity to take advantage of the good features of this type of sonar in a complete clearance system. The sonar would be the same as that proposed in Section 3.1.2.

However, after having detected, located and classified a target as a mine or mine-like, the SWATH would slow or stop and navigate toward the object. Neutralization would be done with a vectored boat as discussed in the previous section. The obstacle avoidance sonar would be used to reacquire the target and to vector the boat to the target. This entire method of operation would not be feasible using a towed body. (An exception to this statement would be the short tow scope configuration.) Also it

is essential to have excellent target classification in order to minimize the number of neutralization actions. An aheadlooking sonar with higher resolution than the AN/WQS-1 would be desirable but not necessary.

3.2.3 Minehunting Summary

Ideally, the SWATH should be adequately flexible to be configured in any one of several ways for minehunting. Several configuration concepts have been outlined but this treatment is not exhaustive. The ideal equipment does not exist, but equipment does exist which could be used for concept testing and evaluation, and better equipment substituted when it is developed or becomes available. There is a wide variation in the sizes and weights of the several possible equipment suites. However, it would seem that an MCM equipment allowance of 5 t should be acceptable for any of the system concepts discussed.

Personnel required will depend on the particular system. (Boat crews are not considered here.) For channel mapping using post-operation data analysis, a crew of two should suffice. For clearance type of operations, a crew of four probably would be needed for the sonar in order to provide adequate relief. For neutralization, if divers are employed, at least four would be needed. It would seem prudent to allow a 1 t payload for MCM personnel.

3.3 MCM EQUIPMENT SUITE CONCEPTS USED BY NOSC AND DTNSRDC FOR THEIR SWATH CONCEPT STUDIES

As was stated earlier, the emphasis for the SWATH study was on the SWATH craft and not on the MCM equipment suite. However, in order to conduct the craft concept studies both NOSC and DTNSRDC had to assume equipment suites in order to determine the necessary payload. Each group was free to select combinations of equipment such as those described in this section of the report. The NOSC suites are shown in Table 3.1 and the DTNSRDC suites are shown in Table 3.2. Each includes suites for bottom mapping (with no neutralization), and for minehunting, (with mine neutralization).

In general the DTNSRDC suites are heavier (and more costly) than the NOSC suites. This results from DTNSRDC's decision to use the AN/SSN-2 navigation system, heavier (and sometimes more) sonars, heavier neutralization vehicles and to carry 16 charges (as opposed to six by NOSC).

It should be emphasized that the specific choice of equipment is not critical to the study, provided that the SWATH configuration selected is capable of carrying the required payload. The resulting SWATH craft concepts range from 20 to 56 t displacement to carry payloads from 3 to 18 t.

TABLE 3.1
NOSC MCM EQUIPMENT SUITES

FUNCTION	Surveillence only (No Neutralization)		Hunting and Neutralization: Option A Sidelooking Sonar		Hunting and Neutralization: Option B Aheadlooking Sonar	
	Unit	Weight	Unit	Weight	Unit	Weight
NAVIGATION	Commercial	1000	Commercial	1000	Commercial	1000
SONAR	SLS OAS	4000 1000	SLS OAS	4000 1000	ALS (VDS)	4000
NEUTRALIZATION	(None)	0	Z-Boat plus 6 charges	3000	Z-Boat plus 6 charges	3000
TOTAL	6000 lb (2.7 t)		9000 lb (4.0 t)		8000 lb (3.6 t)	

NOTES:

1. Commercial Navigation: Loran-C plus one precision microwave system on RAYDIST. GPS when available.
2. SLS (Sidelooking Sonar): One of the following: C-MK-1, DUBM-41B, AN/AQS-14, commercial SLS, or new design SLS.
3. OAS (Obstacle Avoidance Sonar): Either AN/NQS-1 or one of the commercial fishing sonars.
4. ALS (Aheadlooking Sonar): AN/SQQ-16 or a modern version.
5. Z-Boat: Conventional inflatable boat with charge saddle and winch. Manned or radio controlled. Charges weigh about 350 lb each.

TABLE 3.2
DTNSRDC EQUIPMENT SUITES

FUNCTION	Option A Minehunting Only		Option B Minehunting Limited Neut.		Option C Two Step System: Hunter		Option C Two Step System: Killer		Option D	
	Unit	Weight	Unit	Weight	Unit	Weight	Unit	Weight	Unit	Weight
C^3NAV	SSN-2	3000	SSN-2	3000	SSN-2	3000	SSN-2	3000	SSN-2	3000
SONAR	SQQ-16	4800	SLS	3200	SLS	3200	ALS (Hull)	6000	ALS (Hull)	6000
	WQS-1	1000	WQS-1	1000	WQS-1	1000	WQS-1	1000	SLS	3200
	C-MK-1	3200	C-MK-1	3200	SQQ-14	17,000				
NEUTRALIZATION	(NONE)		PAP-104 (2 units)	5000			PAP-104	5000	MNS	26,400
			16 charges	4800			16 chgs	4800	10 chgs	1,600
			MK-103 sweep	3000			MK-103	3000	10 chgs	
TOTAL	12,000 lb (5.4 t)		20,000 lb (8.9 t)		24,200 lb (10.8 t)		22,800 lb (10.2 t)		40,200 lb (17.9 t)	

4.

A FEASIBILITY STUDY OF SWATH SUPPORT CRAFT FOR COASTAL MCM OPERATIONS (DTNSRDC)

The David Taylor Naval Ship Research and Development Center was requested by the SWATH Task Group of the Naval Studies Board to determine the practicality of employing SWATH craft as platforms upon which a variety of specified MCM equipments could be carried, and to comment on their feasibility and cost. However, only general guidance was provided as to the desired combination of MCM equipments. No particular operational concept was specified other than to keep the SWATH MCM support craft as small and as inexpensive as possible. Consequently, the approach taken was to postulate four representative suites of currently available MCM equipment and to size SWATH craft for four payload options.

Payload Option	Function(s)	Payload Weight
DTNSRDC A	Minehunt only	5.0 long tons
DTNSRDC B	Minehunting with Limited Neutralization	9 long tons
DTNSRDC C	Two Craft Hunter/Killer System	11 long tons
DTNSRDC D	Independent Operation MCM Craft	18 long tons

Of these four options, emphasis was placed on Option B because it was consistent with our understanding of the concept of operations being formulated by the SWATH Task Group of the Naval Studies Board. The scope of the investigation included the development of a weight breakdown, from which the acquisition cost could be estimated, and the determination of gross geometry and powering requirements. No attempt was made to develop a main deck arrangement of the MCM equipment because such an arrangement requires a more thorough understanding of the concept of operations, and would also be dependent upon the specific choice and details of any MCM equipments.

4.1 MINEHUNTING WITH LIMITED NEUTRALIZATION

The starting point selected for this ship sizing investigation was the recently constructed SWATH craft, SUAVE LINO, which was built by the Poole Boatyard in San Diego, California for private use. This craft, shown in Figure 1, is constructed of aluminum and, as originally built, had the following principal characteristics.

Submerged Length Overall	61.5 ft
Maximum Beam Overall	30.0 ft
Hull Spacing Between Centerlines	25.0 ft
Design Draft	5.5 ft
Cross-Structure Clearance	4.0 ft
Light Ship Weight	38.9 long tons
Variable Loads	2.7 long tons
Full Load Displacement	41.6 long tons

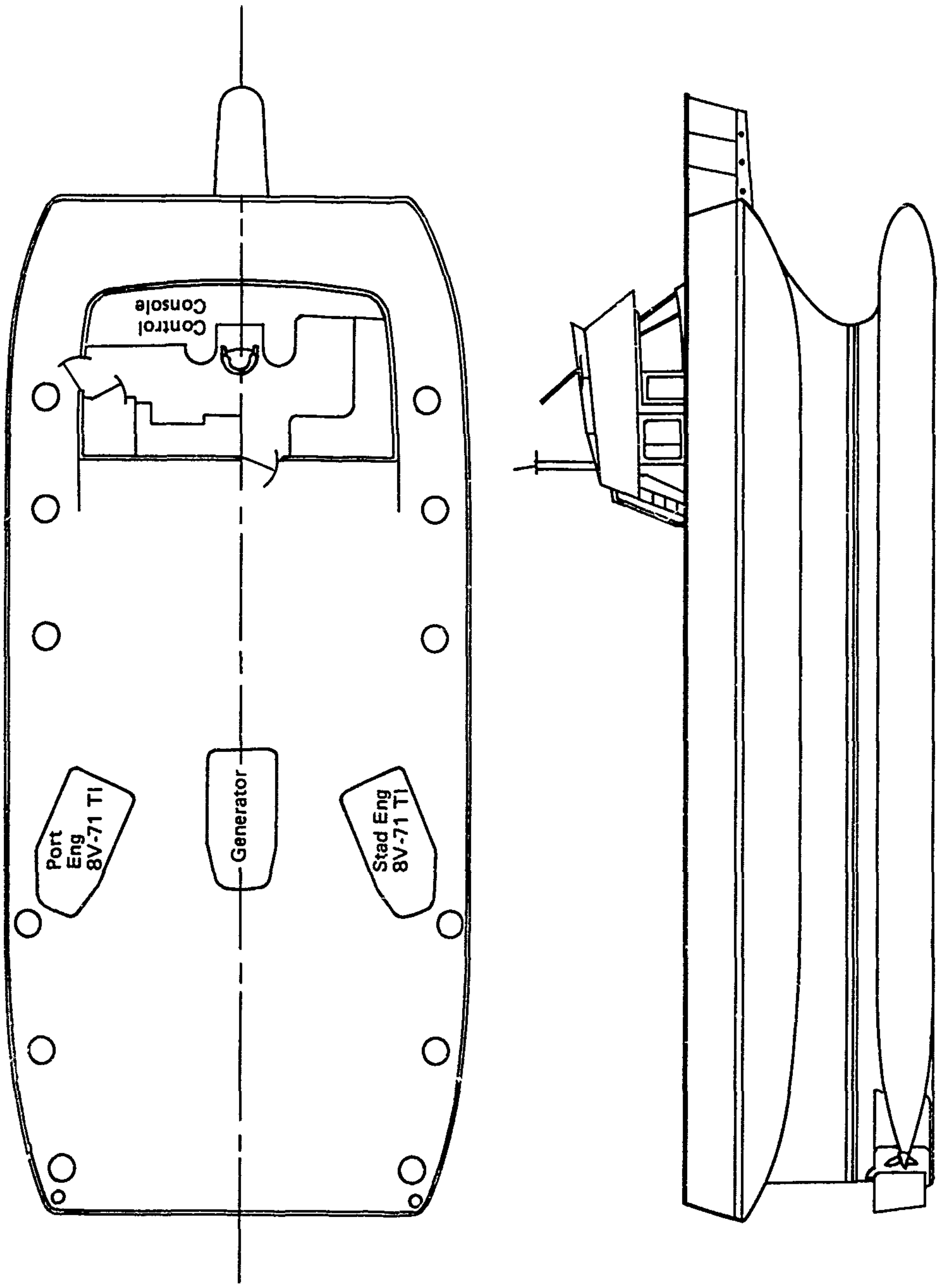
During September and October of 1981 the SUAVE LINO underwent a series of full-scale trials as part of the Coast Guard's continuing effort to accumulate data on advanced marine vehicles as possible replacements for their present fleet of cutters. The tests completed thus far include: speed/power performance, maneuvering, dynamic stability and seakeeping and structural responses.* DTNSRDC served as the Coast Guard's technical manager for these tests. This data indicates that the seaway performance of the SUAVE LINO is impressive and that the craft appears to be well suited for coastal operations at all speeds up to its maximum speed of 18 kt. On one occasion the craft operated in high state 5 seas without sustaining damage. A program of operational evaluation tests of the SUAVE LINO by various potential Navy users is planned to begin soon.

However, while the SUAVE LINO gives credibility to claims about the capabilities and advantages of small SWATH craft, the SUAVE LINO configuration will require certain modifications to make it suitable as a support craft for the DTNSRDC Option B MCM payload. The most obvious deficiency is that the variable load carrying capability of the SUAVE LINO is only 2.7 long tons, while the estimated useful load (payload plus variable loads) to support the DTNSRDC Option B payload is about 13.5 long tons. The least costly way of obtaining that payload capability in a

*Jones, Michael P., "Test and Evaluation of the Ocean Systems Research 64-Foot SWATH Demonstration Craft," NAVSEADET Norfolk Report No. 6660-91, February 1982.

FIGURE 1

MAIN DECK & OUTBOARD PROFILE, SUAVE LINO



derivative of the SUAVE LINO design is to increase the buoyant volume of the lower hulls and struts without changing hull spacing or hull length. Such an approach can be taken to increase the payload of the SUAVE LINO because the existing main deck area of 1850 sq ft seems adequate for the DTNSRDC Option B payload.

Among the major naval architectural considerations to be resolved in such a modification to the buoyant volume of a SWATH is the need to provide adequate intact pitch and roll stability. The latter is controlled by the proper combination of strut waterplane area and hull spacing. In modifying the SUAVE LINO design to carry the DTNSRDC Option B payload, the ratio of waterplane area to total craft displacement was held constant. This approach made it possible to maintain the transverse metacentric radius constant, as displacement was increased, without any change in hull spacing. Moreover, a constant value of strut waterplane area per ton of displacement will tend to keep the ratio of wave exciting forces to displacement about the same as that for the original SUAVE LINO. The magnitude of the wave exciting forces is an important factor affecting the seakeeping performance of a SWATH.

The first step in modifying the SUAVE LINO design was to increase strut length by 5 ft, thereby bringing the midpoint of the strut (and, by extension, the upper box) in line with the longitudinal center of buoyancy of the lower hulls. It was thought that this would facilitate arrangement of the main deck. The strut was lengthened in such a way that the longitudinal center of flotation (LCF) of the new strut also coincides with the longitudinal center of buoyancy (LCB) of the lower hulls. The lack of separation between LCB and LCF will tend to make the seakeeping behavior of a SWATH unaffected by ship heading with respect to the waves. The increase in strut waterplane area was 7.4 percent, which makes it possible to increase the total craft displacement by 7.4 percent, i.e., to 44.7 long tons. Because of the longer strut there is a rise of 2.5 ft in the longitudinal metacentric height, and therefore an increase in hydrostatic pitch stability, even with the increased displacement.

It is assumed that strut immersion should be kept the same as for the original SUAVE LINO, or 1.65 ft. As a result of the increased strut length, the strut buoyancy increased by 0.4 long ton. Thus, 2.7 of the total 3.1 long tons of additional displacement volume must be obtained by modifying the lower hulls. This was done by making the lower hull cross-section elliptical while retaining the same longitudinal sectional area distribu-

tion as that for the SUAVE LINO. A hull vertical axis of 3.34 ft was chosen to limit the draft to the maximum desired value of 5.0 ft. The required hull horizontal axis length to provide 2.7 long tons additional buoyancy is 4.77 ft. The ratio of the length of the major and minor axis is thus 1.43:1. For this modified configuration 87.6 percent of the total buoyant volume would be in the lower hulls and 12.4 percent in the immersed portion of the struts.

Based on previous SWATH investigations, the limit of practicality for a SWATH lower hull elliptical cross-section was judged to be 1.8:1. Compared to a 1.34:1 ellipse, a 1.8:1 ellipse provides 25.9 percent more cross-sectional area. It follows that the buoyant volume of a lower hull comprising a 1.8:1 elliptical cross-section will be 25.9 percent greater than that of a hull with a 1.43:1 ratio. The increase in the buoyant volume of the two lower hulls is thus 9.95 t. To keep the ratio of waterplane area per ton of displacement constant, there must be a corresponding increase in strut thickness of 25.9 percent. (The resulting increase in strut buoyancy will be 1.4 long tons.) Thus, by adopting 1.8:1 elliptical lower hulls the displacement of the SUAVE LINO can be increased to 56 t. The increase in strut and lower hull structural weight required to provide such volume is estimated to be about 2 long tons.

Before deciding on the exact lower hull and strut geometry for a SWATH to support the DTNSRDC Option B payload, it was necessary to make an estimate of light ship weight. Because no weight breakdown is available for SUAVE LINO, the following weight estimate has been developed based on the "Light Ship" weight given in NAVSEADET Norfolk Report No. 6660-80 of May 1981.

Structure	23.7 long tons
Propulsion	8.3 long tons
Electric, Communications Control Auxiliaries Outfit	6.9 long tons
Subtotal--"Light Ship"	38.9 long tons
Variable Loads	2.7 long tons
Full Load Displacement	41.6 long tons

Three adjustments were then made to the above weight estimate. First, the structural weight must be increased by 5 percent to allow for local reinforcement of the structure in high stress areas. Second, the 900-hp (total) propulsion system on the SUAVE LINO would be replaced with two Harbor Master Model F-3135 fixed-stem, steerable, right-angle propulsion units providing a total of 350 hp. Third, the weight of auxiliary systems would be reduced by an estimated 0.9 t because rudders and steering gear actuators are not needed with the outdrive propulsion units. The revised weight breakdown is shown below.

	Modified SUAVE LINO	DTNSRDC Option B
Structure	24.9 long tons	27.0 long tons
Propulsion	7.0 long tons	7.0 long tons
Electric, Communications Control, Auxiliaries, Outfit	6.0 long tons	6.5 long tons
Subtotal--"Light Ship"	37.9 long tons	40.5 long tons
Variable Loads	3.7 long tons	13.5 long tons
Full Load Displacement	41.6 long tons	54.0 long tons

The light ship weight for a SWATH craft to support the DTNSRDC Option B MCM payload is estimated to be about the same as the adjusted light ship weight for the SUAVE LINO, plus 2 additional long tons of structure for the enlarged lower hulls and thicker struts. The estimated breakdown of variable loads is:

DTNSRDC Option B MCM Payload	9 long tons
Fuel	3 long tons
Crew and Effects	1 long tons
Water/Provisions	0.5 long ton
Subtotal--Variable Loads	13.5 long tons

Therefore, the estimated full load displacement is 54 long tons which means that a useful load fraction of about 25 percent can be achieved. Figure 2 shows the resultant overall craft geometry. Figure 3 is a representative cross-section. The simplified lower hull cross-section shown is equivalent in area to the 1.73:1 elliptical cross-section and should be easier to construct.

FIGURE 2
PLAN VIEW & PROFILE VIEWS, DTNSRDC OPTION B

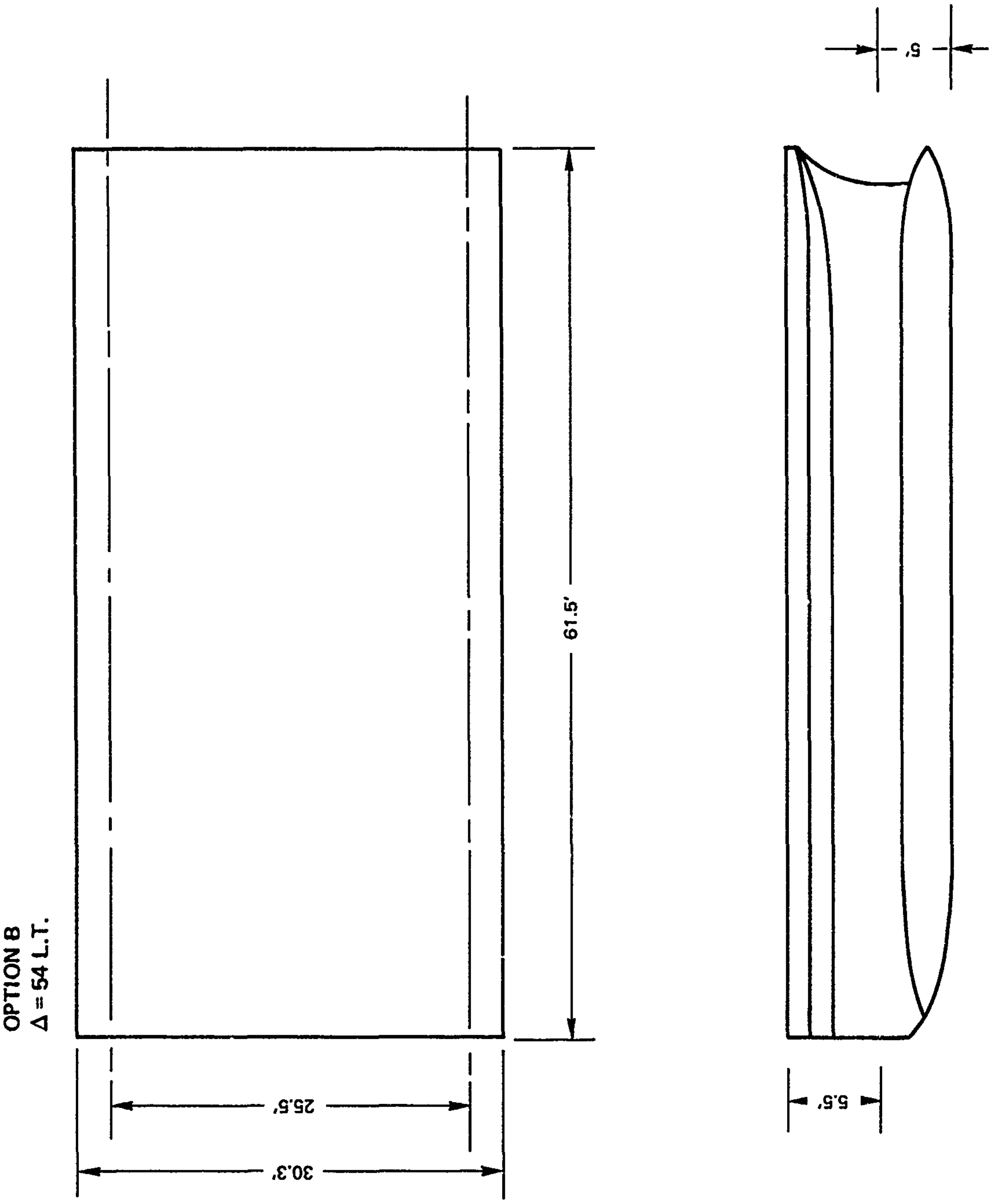


FIGURE 3
HULL CROSS SECTION, DTNSRDC OPTION B

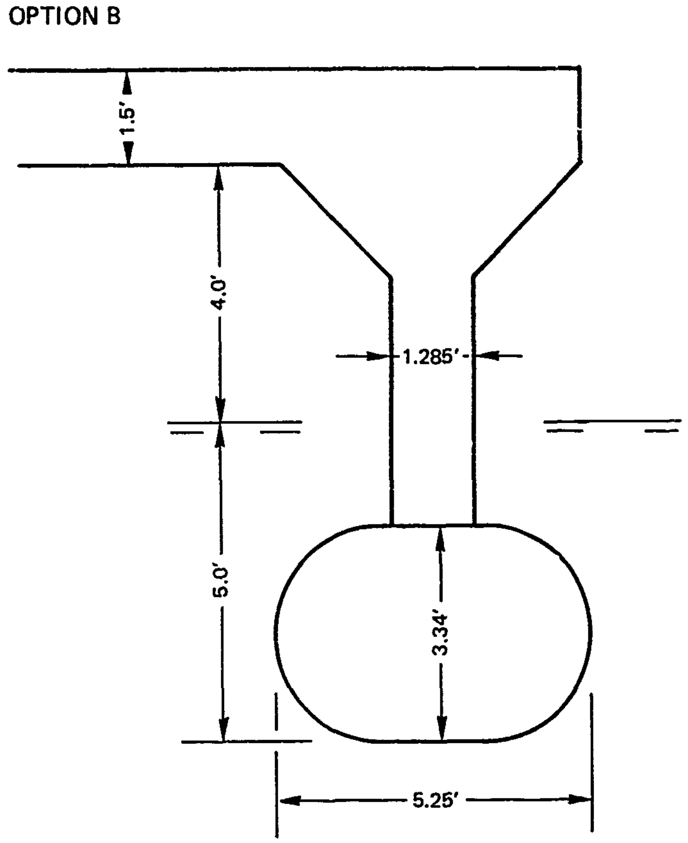


Figure 4 shows details of the proposed propulsion machinery installation which uses the Model 6-71 Detroit Diesel engine and a Harbor Master-type, heavy-duty outdrive. With two of these units the predicted maximum speed is 12 kt. Figure 5 gives the predicted calm-water powering performance for DTNSRDC Option B configuration. This prediction is based on an assumed propulsive efficiency of 0.60 and a transmission efficiency of 0.96.

No attempt has been made to estimate the acquisition cost of the DTNSRDC Option B MCM SWATH. However, it is "rumored" that the cost of the estimate of the designing construction and some modifications to the SUAVE LINO, with its larger diesel engines and right angle drive transmission, was somewhere between $800,000 and $1 million. The quoted cost for a Harbor Master Model F-3175 propulsion unit, complete, is about $50,000. DTNSRDC has received a letter from Mitsui Engineering and Shipbuilding Co. which states that their experience in building SWATH ships leads them to conclude that a SWATH will cost about 10 percent more than a monohull designed for the same payload, speed and endurance and using comparable materials, outfit and standards.

4.2 OTHER OPTIONS

Based on the DTNSRDC Option B configuration, the size of SWATH craft required to support the A and D MCM payload options can be estimated. First, a total useful load was estimated for each option:

	DTNSRDC Option A	DTNSRDC Option D
MCM Payload	5.0 long tons	18 long tons
Fuel	3 long tons	6 long tons
Crew & Effects	1 long ton	1.5 long tons
Water/Provisions	0.5 long ton	1 long ton
SW Ballast		4.0 long tons
Total Useful Load	9.5 long tons	30.5 long tons

For the smaller Option A craft, the strut thickness and lower hull cross-section were kept the same as DTNSRDC Option B, but the length dimensions were reduced by 10 percent. It is estimated that this would reduce the structural weight by somewhat less than 10 percent. The propulsion units were assumed to be the same as DTNSRDC

FIGURE 4
HEAVY DUTY OUTBOARD DRIVE INSTALLATION

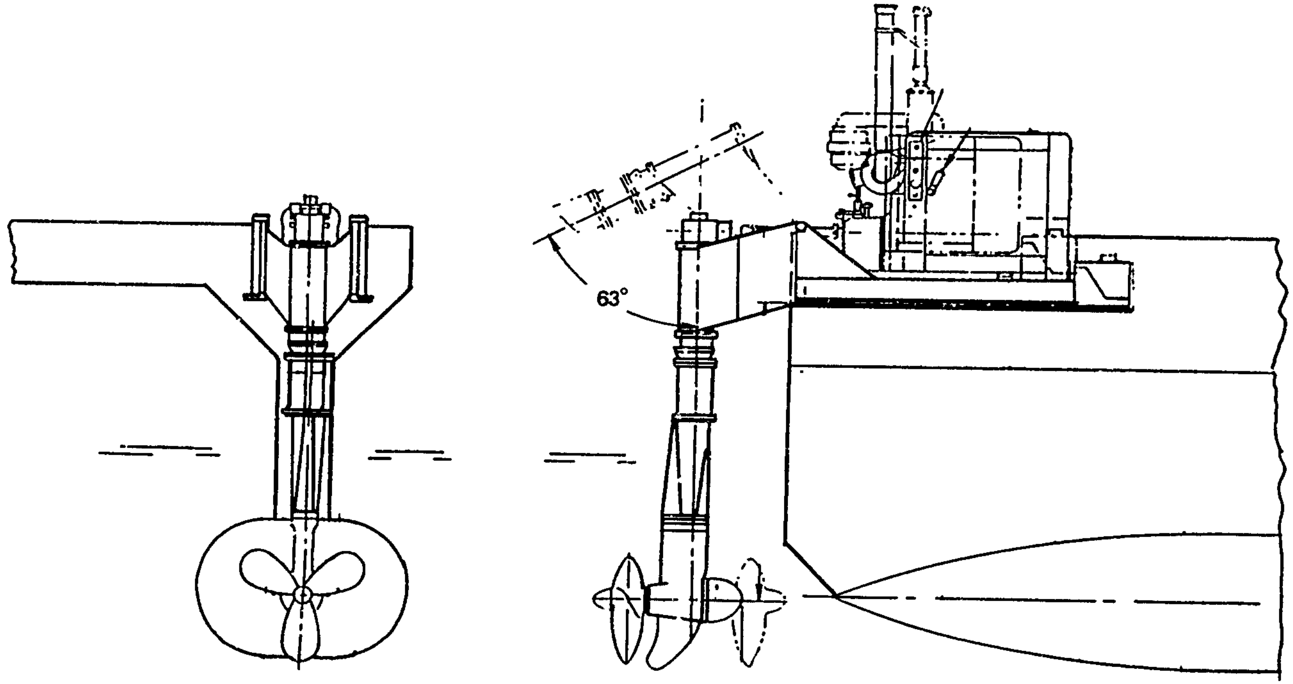
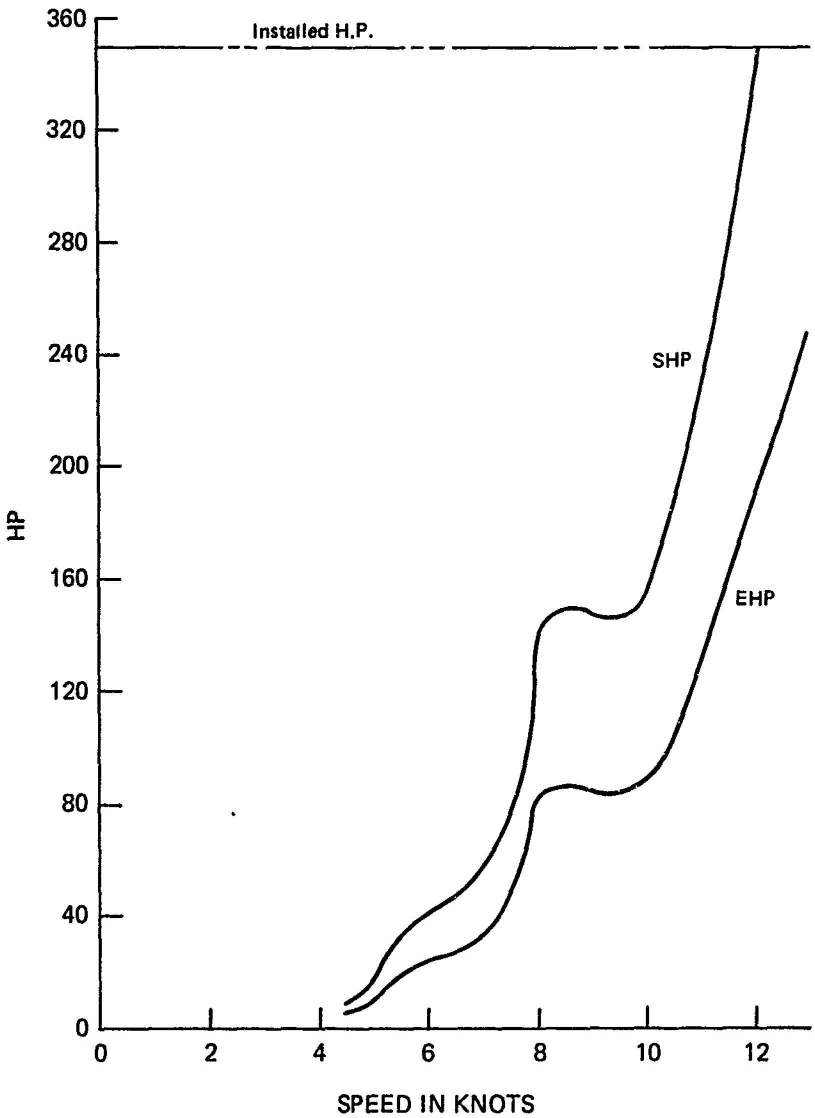


FIGURE 5

PREDICTED POWERING REQUIREMENT FOR DTNSRDC OPTION B



Option B, because the powering requirement at 12 kt is about the same. The light ship weight was estimated to be 38 t, with the breakdown of weights shown below:

	DTNSRDC Option A	DTNSRDC Option D
Structure	25 long tons	38 long tons
Propulsion	7 long tons	7 long tons
Electric, Communications Control, Auxiliaries, Outfit	6 long tons	9 long tons
Subtotal "Light Ship"	38 long tons	54 long tons

For the larger DTNSRDC Option D craft, the geometry has been derived from the modified SUAVE LINO using elliptical hulls of 1.8:1 cross-section, which results in a full load displacement of 56 t. This geometry was scaled up until the useful load capacity increased to the required 30.5 t. Structural weight has been assumed to be the same as for DTNSRDC Options A and B. Because of the considerably greater payload, it was estimated that the combined weight of outfit plus electrical and auxiliary systems would increase by 50 percent. The resulting light ship weight estimate is shown above.

Although DTNSRDC Option D has a 56 percent larger displacement than Option B, the difference in overall length is only 6.5 ft. The useful load fraction for Option D is 36 percent, compared with 25 percent for Option B and 20 percent for Option A. It is estimated that Option D will have a maximum speed of 11 kt, while both Options A and B will have a maximum speed of 12 kt. DTNSRDC Option C was not investigated because the payload weight differs by only 2 t from that for DTNSRDC Option B.

4.3 SEAKEEPING ABILITY OF DTNSRDC SWATH, OPTION B

The Davidson Laboratory, Stevens Institute of Technology, computer program was used to estimate the seakeeping ability of this SWATH option. This program computes the absolute and relative motions, the vertical velocities and accelerations at any point on the hull for all speeds and headings relative to a seaway. In addition, the program computes the number of wave-cross structural contacts and impacts per hour, the number of propeller emergences per hour and the 2-hr motion sickness index (MSI). The

Ochi two-parameter wave spectrum family is applied where, for a given significant wave height, nine modal periods are used. Applying a suitable weighting factor, the results of each motion output are averaged for all wave heading and modal periods.

The geometry and weight distributions were supplied by DTNSRDC and the more pertinent computed seakeeping results are given in Table 2.3. These results are presented for a passive pitch, heave and roll control system. The tabulated results will be considerably reduced by the use of an active hull mounted fin control system--especially at high speeds.

Examining Table 2.3, it is seen that the motions and accelerations of the 54-long-ton SWATH are quite modest--even in a Sea State 5 where the significant wave height is 10 ft. The roll angle amplitude is only 2.9°, while the pitch amplitude is 3.5° and the center-of-gravity heave amplitude is 4.9 ft. Further, the calculated 2-hr MSI is only 4 percent. For a significant wave height of 5 ft (Sea State 3), which is a more realistic sea environment for MCM inshore operations, the motions and accelerations are approximately half those in a 10-ft sea and the 2-hr MSI is now just 1 percent. These small motions and accelerations provide a comfortable environment for the crew and do not limit the satisfactory operation of the MCM instrumentation package.

Although not tabulated herein, the computer output shows the absolute motion amplitude of the stern to be approximately 2 ft in a 5-ft significant wave system. This is an acceptable motion for a stern-mounted tow.

It was also found from the computer analysis that, in a 5-ft significant wave height, there was little evidence of deck slamming or propeller emergence.

5.

FEASIBILITY STUDY OF A HARBOR AND COASTAL SWATH MCM BOAT (NOSC)

The Naval Ocean Systems Center was requested by the MCM Task Group of the Naval Studies Board, National Research Council to investigate the feasibility of utilizing small SWATH boats in a harbor and coastal MCM role. The SWATH platform was selected for study because the concept has demonstrated excellent seakeeping characteristics in larger sizes and because the technology is conventional, leading to the possibility of low cost production boats. As a consequence, the primary objectives of this study were to assess the seakeeping characteristics of these small boats and provide an estimate of the cost of construction.

A secondary objective of assessing air transportability could not be met because there was not sufficient time to carry the study to the depth required for a proper evaluation of this parameter. This issue, however, is not considered critical to determining the feasibility of the concept, and can be better addressed in follow-on studies.

The study was divided into five areas: Requirements, Size, Geometry, Seakeeping Performance and Cost. The approach taken to develop information in each of these areas is covered below.

5.1 REQUIREMENTS

Requirements cover the principal operational capabilities of the boat such as payload, endurance, habitability, etc. These factors play a crucial role in determining the size or displacement of a boat and therefore its cost. Guidance in this area was provided by the Naval Studies Board. As a result, the requirements listed as Option A, Table 5.1, were generated. This option provides the capacity to carry a full complement of minehunting gear, and sufficient personnel and fuel to remain on station for a substantial period of time.

The requirements of Option B were generated in order to assess the impact of reduced capabilities on size and cost. It also led to a powering and seakeeping assessment of smaller hull forms.

5.2 SIZE

Size refers to the basic dimensions of the platform and its displacement. These parameters are derived by assuming a full load displacement which will accommodate the desired payload weight, then estimating the value of each of the weight groups (1-6) for a craft of the implied size. The process is iterated until the sum of all light ship and load weights equals the displacement. Table 5.2 presents the breakdown of weights found for the Option A and Option B payload requirements. The structural weight was assumed to be 55 percent of the design load displacement. Propulsion and electrical system weights were estimated by selecting production units from available catalogs, using the weights provided and adding sufficient weight to account for ancillary equipment such as controls, cables, cooling, etc.

The weights of groups 4, 5 and 6 were simply estimated. In order to cover errors in these rough numbers, a 20 percent margin was added. Note that this effectively results in a final structural fraction of 66 percent, which is quite conservative. It is also interesting that the boat sized to meet the requirements of Option B is substantially smaller than the Option A boat.

The propulsion system selected for these small MCM boats is somewhat unique. It consists of two 235 hp OMC (Johnson) "Sea Drive" outboard motors modified to incorporate a long shaft and an increased lower drive reduction ratio. These units are very light weight (about 600 lb versus 4300 lb for a diesel system) and low cost (about $3,000 to $4,000 in production versus $30,000+ for the diesel system). The long shaft and extra lower-end speed reduction are estimated to cost $10,000 to $15,000 per unit in small special order quantities.

The outboards generally exhibit less reliability than marine diesels but their low cost would allow the purchase of one or two sets of spare engines per boat. They are also easy to replace when maintenance is required, allowing most maintenance to be accomplished at shore based facilities. The outboards also eliminate the need for a separate steering system.

TABLE 5.1

SWATH SIZING ASSUMPTIONS

Requirements	Option A	Option B
Payload	5 t	3 t
Endurance	100 nmi at 15 kt 18 hr on station at 6 kt 15% fuel reserve	30 nmi at 15 kts 8 hr on station at 6 kt 15% fuel reserve
Personnel	3 crew, 4 sonar technicians	3 sonar, 2 sonar technicians
Hotel Facilities	2 bunks 1 head 1 small reefer	1 bunk 1 head 1 small reefer
Electrical Requirements	10 kW	10 kW

TABLE 5.2

WEIGHT ESTIMATE FOR NOTIONAL MCM CRAFT

Weights	Option A	Option B
Group 1 - Hull Structure	18.2 t	13.0 t
Group 2 - Propulsion	1.5 t	1.5 t
Group 3 - Electrical	0.6 t	0.6 t
Group 4 - Navigation/Communications	0.4 t	0.4 t
Group 5 - Auxiliary Systems	0.5 t	0.5 t
Group 6 - Deck Fittings/Habitability	0.6 t	0.5 t
	21.8 t	16.5 t
Margin (20 percent)	4.4 t	3.3 t
Fuel	1.3 t	0.4 t
Personnel	0.6 t	0.5 t
Payload	5.0 t	3.0 t
Design Load Displacement	31.1 t	23.7 t

Figure 5.1 shows the effect of structural fraction (structural weight divided by displacement) on the size of the boat. SSP KAIMALINO at 58 percent and Marine Ace at 33 percent probably bracket the upper and lower bounds of this parameter. Note that decreasing the structural fraction from 66 percent to a modest 45 percent reduces the size of a boat meeting the "A" requirements from 33 t to 20 t.

5.3 GEOMETRY

Figures 5.2 and 5.3 show conceptual arrangements for 20 t multi-strut (two struts per side) and single-strut (one strut per side) SWATH craft. These configurations are shown using fantail towing. Figures 5.4 and 5.5 show conceptual arrangements of 33 t displacement craft in multi-strut and single-strut designs. The configuration in Figure 5.5 depicts an alternative equipment arrangement which would deploy the towed body through a center well.

Table 5.3 provides a comparison of the characteristics of the best single-strut and multi-strut hull forms investigated. The conclusion that can be drawn from the powering and motions perspective is that the differences between these hull forms are down in the noise of our abilities to predict such things. As might be expected, there is not a substantial difference in size although the multi-strut is a little beamier than the single-strut. This is generally the case because multi-strut craft have less waterplane area but are designed to maintain approximately the same transverse metacentric height (GM_T) as the single-strut craft. The required GM_T is achieved by setting the struts a little further apart, resulting in a somewhat larger beam. This can be a slight advantage if more deck space is desirable but there are ways to get this in the single-strut by letting the upper hull overhang the struts a little. It can be a slight disadvantage if beam is undesirable.

FIGURE 5.1

IMPACT OF STRUCTURAL FRACTION ON SIZE

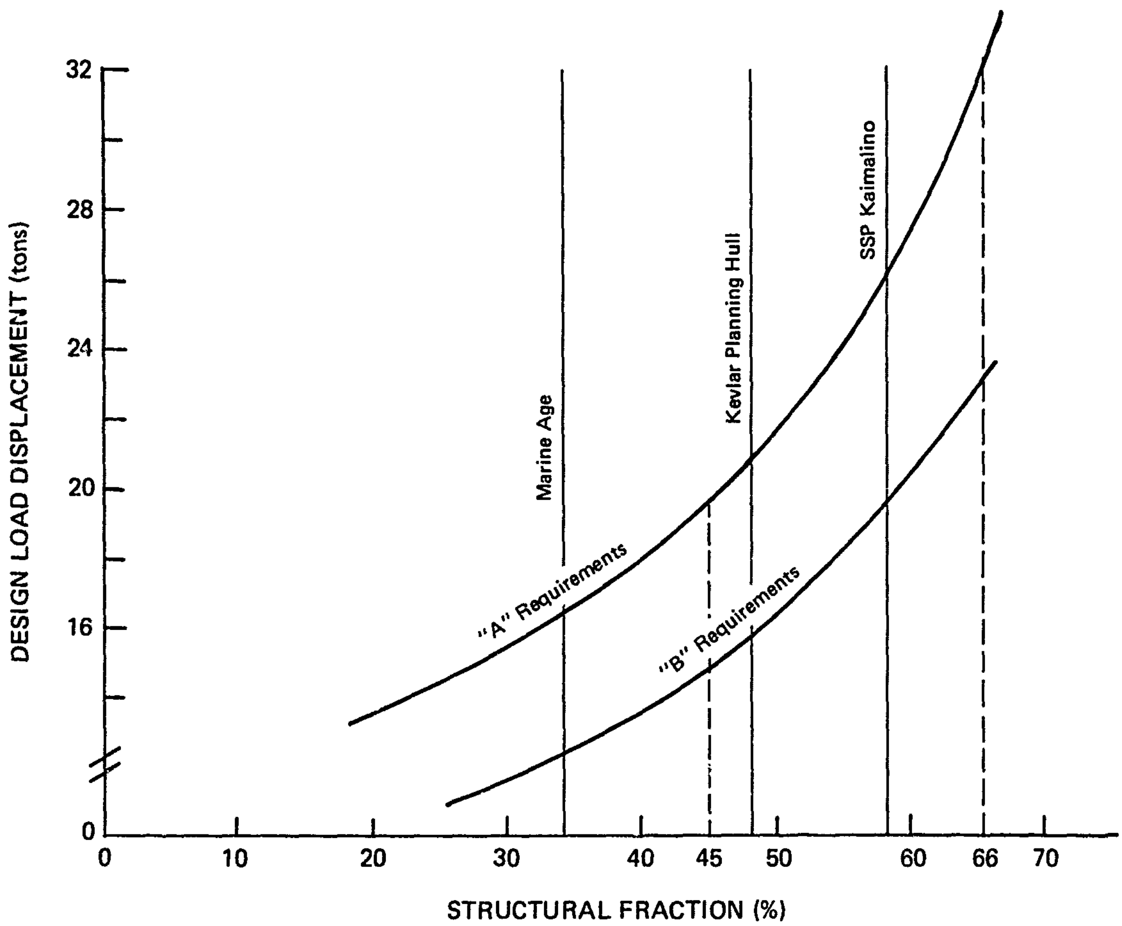


FIGURE 5.2

TWENTY-TON SWATH MCM BOAT

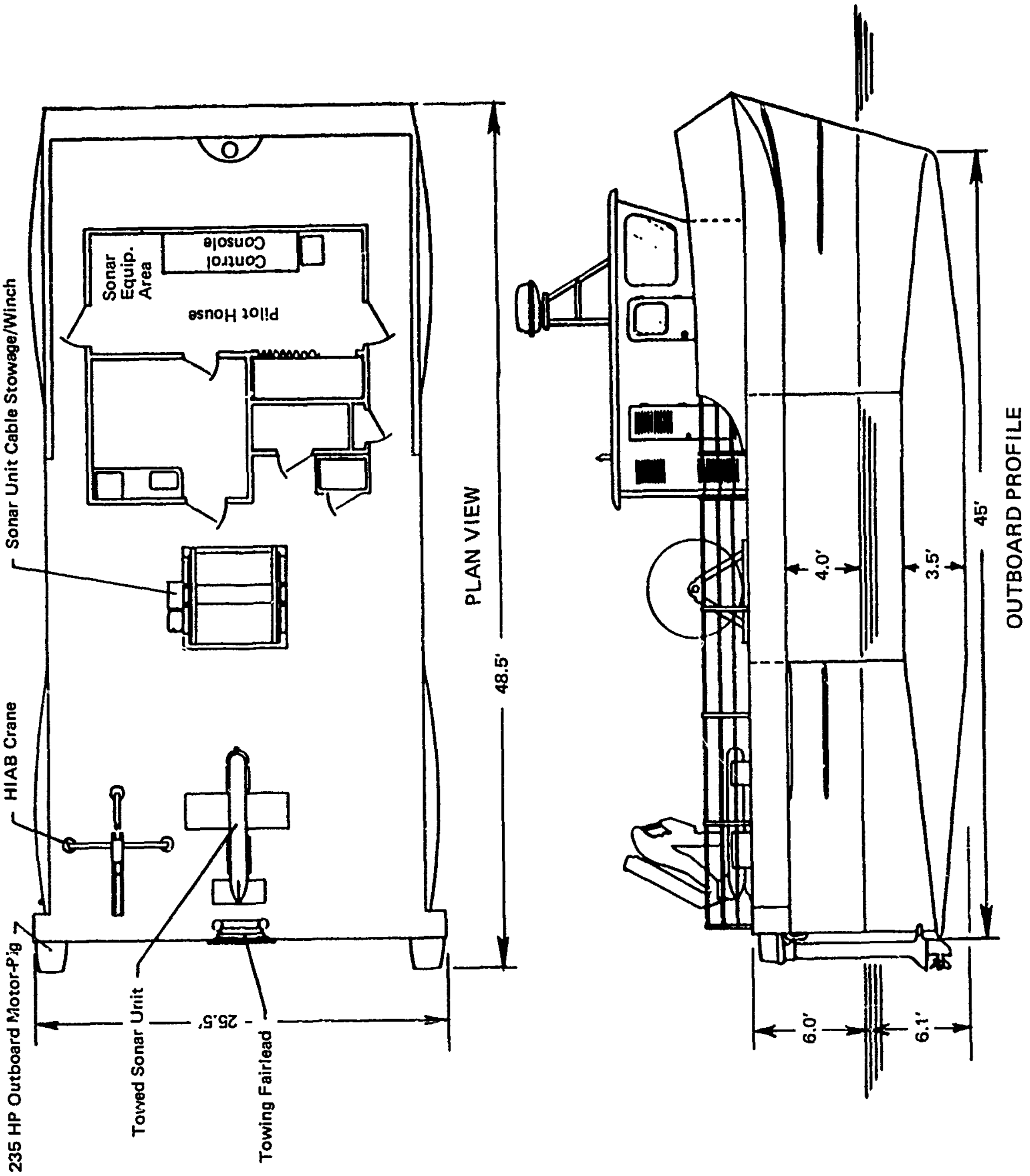


FIGURE 5.3

TWENTY-TON SWATH MCM BOAT

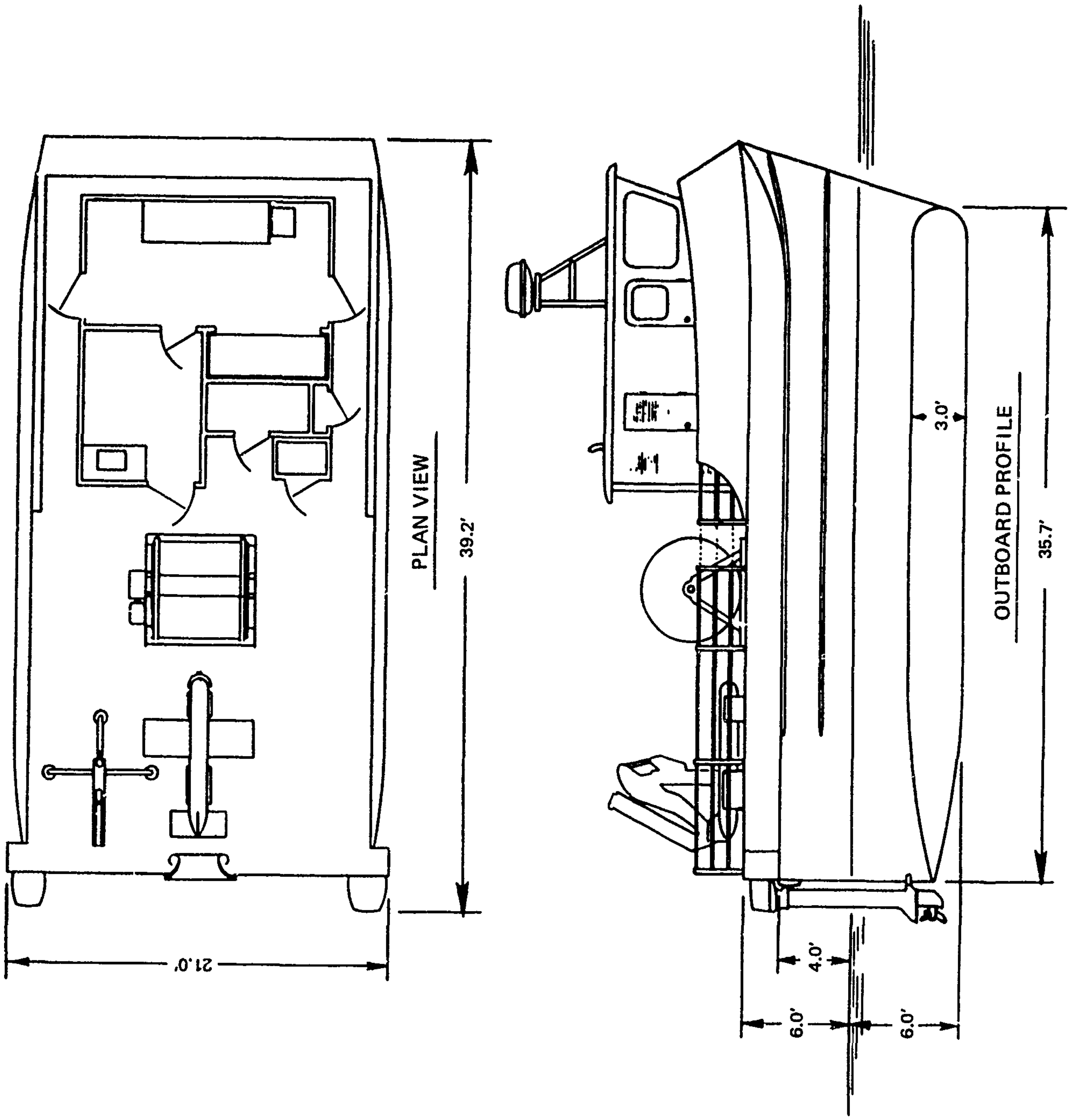


FIGURE 5.4

THIRTY-THREE-TON SWATH MCM BOAT

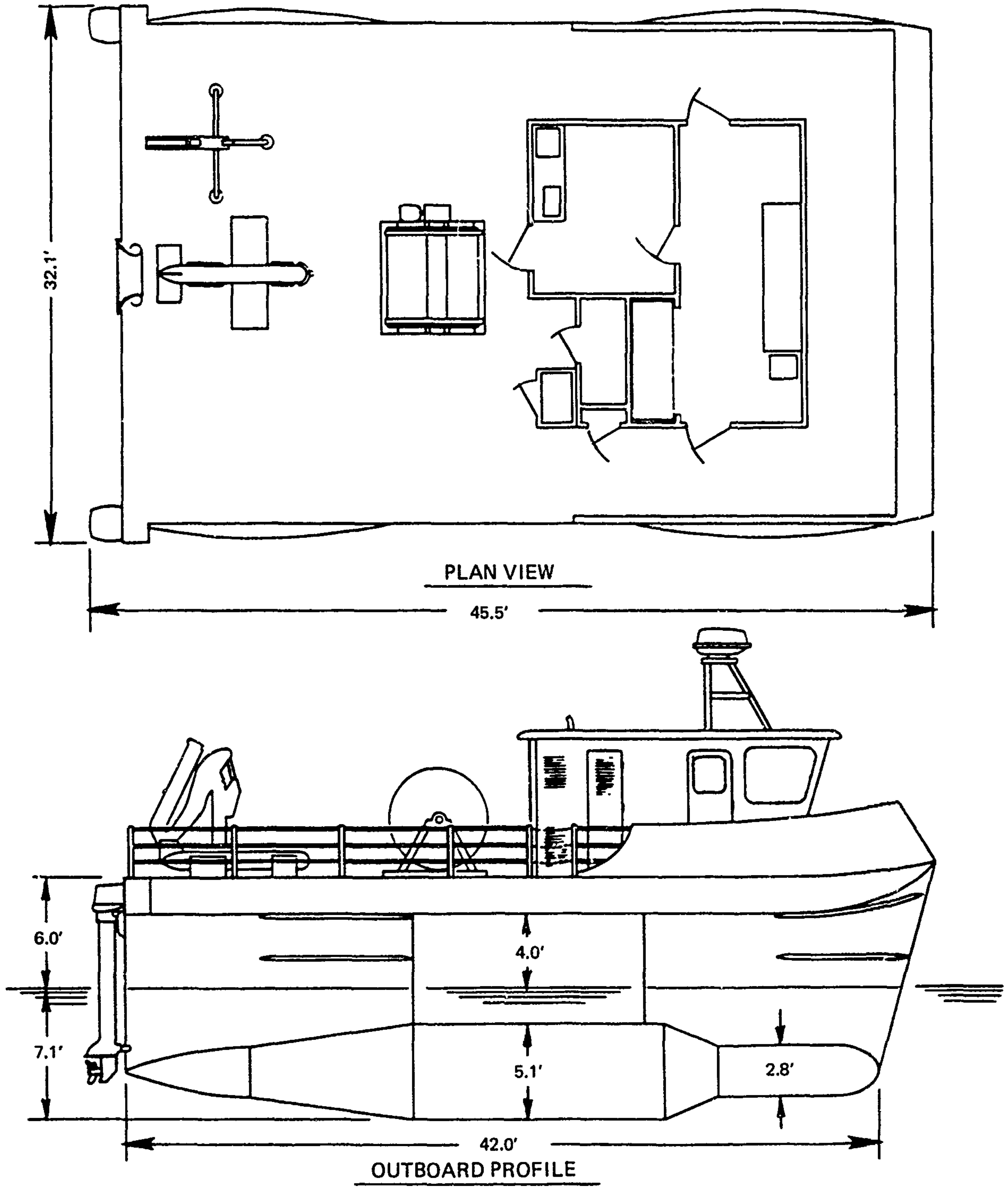


FIGURE 5.5

THIRTY-THREE-TON SWATH MCM BOAT

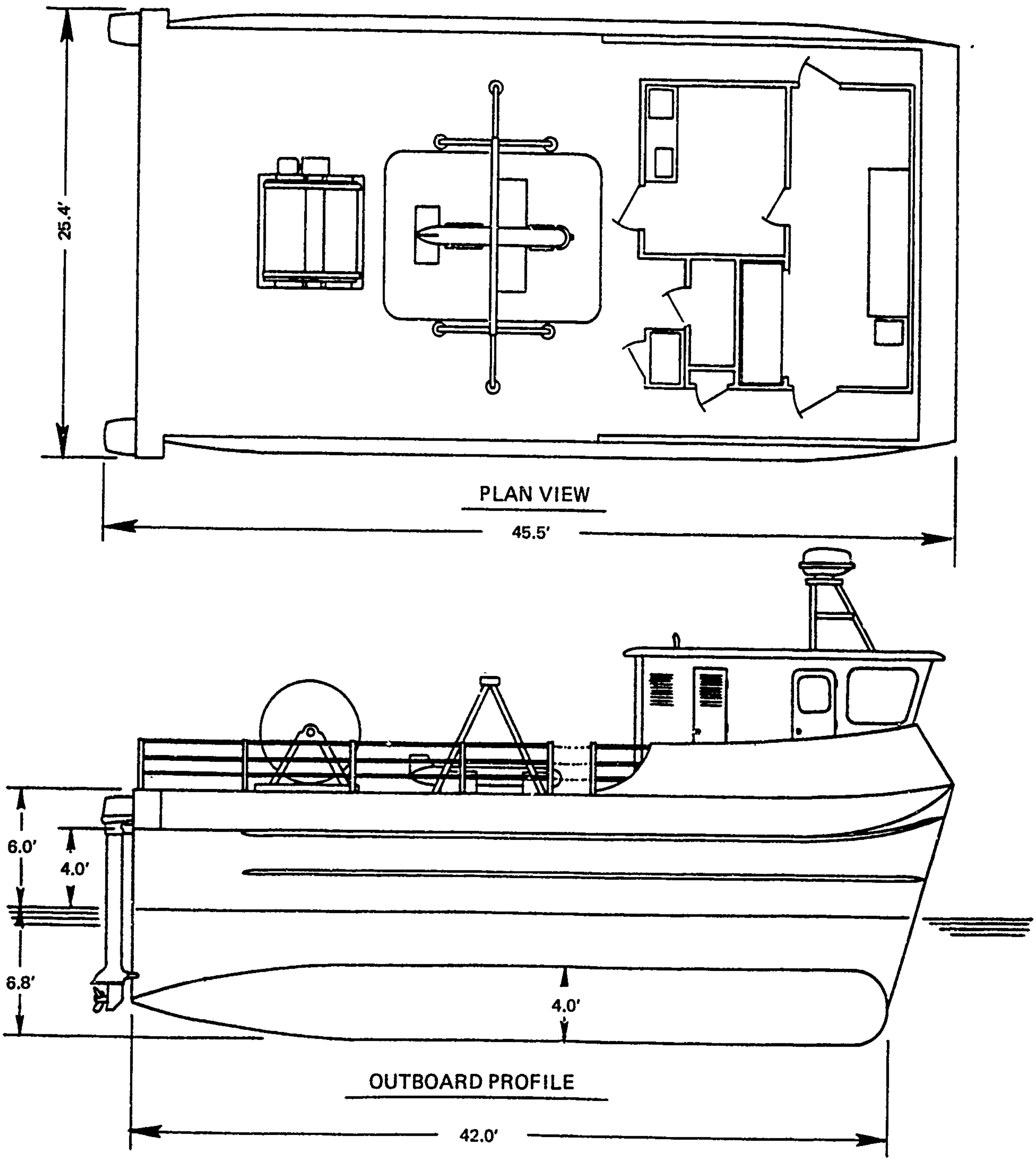


TABLE 5.3

COMPARISON OF PREDICTED MOTIONS FOR SINGLE AND MULTI-STRUT SWATH CRAFT IN RANDOM SEAS WITH A FIVE FOOT SIGNIFICANT WAVE HEIGHT

	Single-Strut (Fig. 5.5)	Multi-Strut (Fig. 5.4)
Powering	416 hp	400 hp
Seakeeping @ 6 kt		
Pitch	1.6°	1.8°
Roll	1.6°	1.9°
Vertical Acceleration	0.04g	0.04g
MSI	1%	1%
Seakeeping @ 15 kt		
Pitch	2.1°	2.1°
Roll	2.0°	3.1°
Vertical Acceleration	0.05g	0.4g
MSI	2%	2%
Overall Dimensions (ft)	42 l x 25.4 b x 6.9 d	42 l x 32.1 b x 7.1 d

5.4 SEAKEEPING PERFORMANCE

Many seakeeping parameters, hull forms and sea conditions were considered in an effort to assess the performance of these small boats. The numbers presented in Table 5.4 are highly averaged and, therefore, they do not reflect best or worst performance. Instead, they give an idea of trends and allow one to make some quick judgments on relative performance. To get these numbers, it was assumed that the boat spends equal amounts of time at all compass headings relative to the sea. It was also assumed that it encounters seas having a 5 ft significant wave height but varying modal periods. The long- and short-period spectra are assumed to occur only infrequently with the mid-period spectra assumed to occur most frequently. All this is averaged together to provide a summary of the performance of each hull form at various speeds.

Pitch and roll are a little less than twice that predicted for the SSP. An automatic control system would substantially reduce these figures even at speeds as slow as 6 kt. In heave, these small craft tend to follow the contour of the ocean surface. Thus, not much difference is seen between them. In 5 ft significant seas the vertical accelerations are on the average a little above the

imperceptible level depicted in Figure 5.6. In 10 ft significant waves, the accelerations are in the tolerable region below the threshold of malaise.

TABLE 5.4

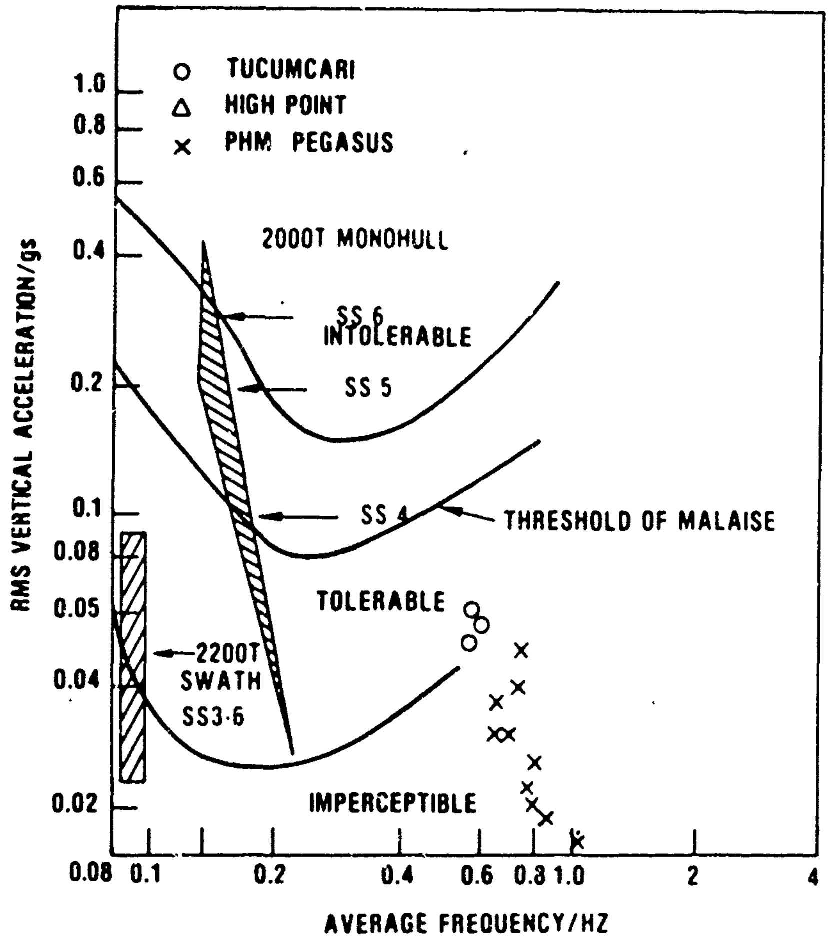
COMPARATIVE SEAKEEPING PERFORMANCE IN RANDOM SEAS WITH A FIVE FOOT SIGNIFICANT WAVE HEIGHT

	SSP (225 t)	MCM "A" (33 t)	MCM "B" (20.4 t)
6 kt			
Pitch	1.0°	1.8°	1.8°
Roll	1.1°	1.9°	1.9°
Heave at LCG	2.1 ft	2.2 ft	2.4 ft
Vertical Acceleration at LCG	0.03 g	0.04 g	0.05 g
MSI	0%	1%	2%
15 kt			
Pitch	1.3°	2.1°	2.5°
Roll	1.7°	3.1°	1.7°
Heave at LCG	2.0 ft	2.2 ft	2.4 ft
Vertical Acceleration at LCG	0.03 g	0.04 g	0.05 g
MSI	0	2%	3%

Seakeeping is also quantified in terms of the MSI factor. This is a measure of the percent of unacclimated male personnel selected at random who can be expected to experience emesis after two hours of exposure to the vertical motions of the platform. This is not a precise measurement but it can be helpful in making comparisons. The conclusion to be drawn from these motions data is that these small SWATH boats are excellent performers in a seaway and they could be expected to be excellent MCM platforms.

A quick look was taken at what happens in relatively heavy seas. A series of studies were run in 7 ft and 10 ft significant waves with the results shown in Table 5.5. Pitch, roll, heave, acceleration and MSI factor all look quite reasonable even for the small 20 t craft. It would appear that the boats would be able to continue to operate at most headings if slamming could be avoided. A motion control system, in addition to reducing motions, can reduce incidences of both slamming and propeller emergence. Bal-

FIGURE 5.6
HUMAN ACCELERATION TOLERANCE BOUNDARIES



lasting bow up, stern down has also been found effective in reducing the effects of heavy seas.

TABLE 5.5

COMPARATIVE SEAKEEPING PERFORMANCE IN RANDOM SEAS WITH A TEN FOOT SIGNIFICANT WAVE HEIGHT

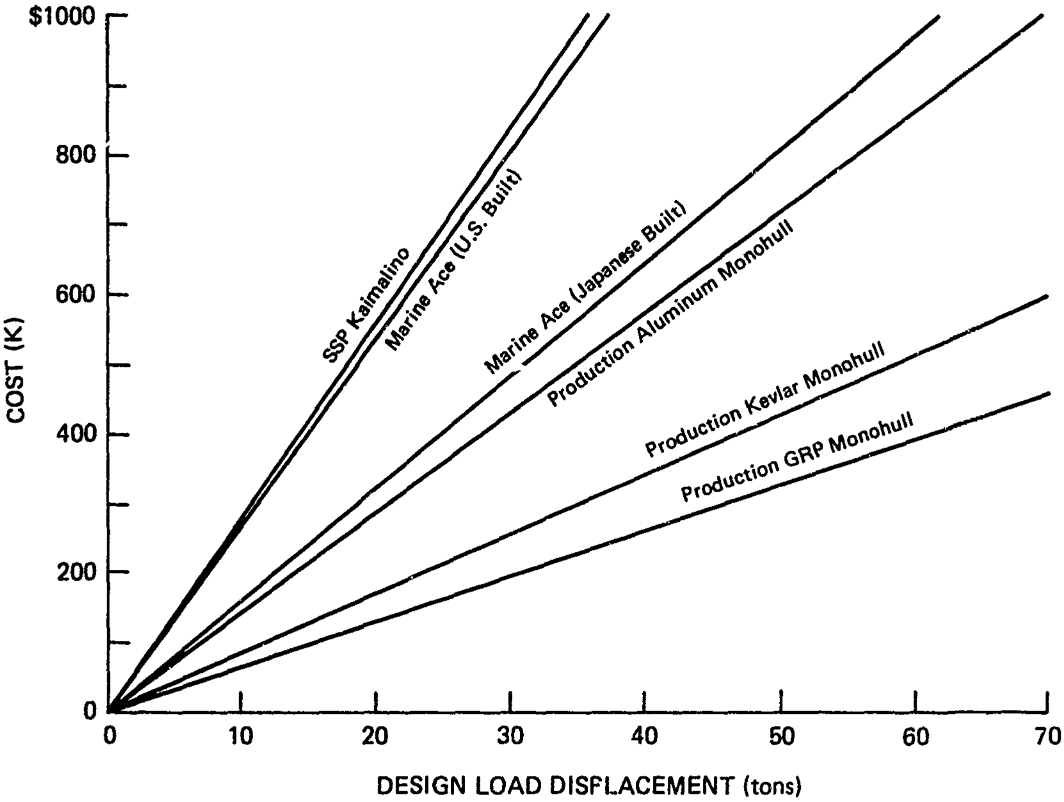
	SSP (225 t)	NOSC "A" (33 t)	NOSC "B" (20.4 t)
6 kt			
Pitch	1.9°	3.2°	3.2°
Roll	1.9°	3.2°	3.2°
Heave at LCG	4.2 ft	4.6 ft	4.9 ft
Vertical Acceleration at LCG	0.05 g	0.07 g	0.08 g
MSI	1%	3%	5%
15 kt			
Pitch	2.3°	3.6°	4.3°
Roll	3.0°	5.2°	2.8°
Heave at LCG	4.1 ft	4.5 ft	4.9 ft
Vertical Acceleration at LCG	0.05 g	0.08 g	0.09 g
MSI	2%	6%	9%

5.5 COST

Cost is clearly a parameter that will play a key role in formulating the conclusions of the SWATH MCM feasibility study. Information has been collected on all of the small SWATH boats built to date and is presented in Figure 5.7. The Marine Ace (18 t) and SUAVE LINO (50 t) are aluminum construction. The upper hull of the SSP (190 t) is aluminum while the lower hulls and struts are high tensile steel. All costs have been escalated to today's dollars. Cost information received from Mitsui on the Marine Ace was for construction in Japan. A factor was generated to account for the higher wage base of U.S. labor in order to estimate the cost of constructing this boat in the United States Design cost has not been included in these data.

Generally speaking, the cost of construction of a boat is proportional to its size provided the technologies

FIGURE 5.7
COST



and production quantities are comparable. This is the case for SSP, SUAVE LINO and Marine Ace, and the data support this conclusion. Because these three boats are moderately sophisticated, one-of-a-kind craft, their cost line probably represents the upper limit on the cost of building the first aluminum MCM boat. In order to develop a feeling for the lower limit of costs, information was collected on production monohulls built of fiberglass (GRP), Kevlar and aluminum. In these small boat sizes, aluminum runs about 50 percent to 125 percent more expensive than GRP.

Boat builders were also asked how much more it would cost to build a comparable one-of-a-kind boat assuming plans were available. The aluminum builders suggested their custom boats would be about 20-25 percent more costly, while GRP and Kevlar builders place this factor at 10-20 percent for SWATH boats. They feel that SWATH costs will not drop with quantity production as rapidly as for monohulls due to the small size of the lower hull and strut interior spaces. This makes it difficult to lay up the hull in a female mold. Keeping in mind that SWATH boats will probably cost somewhat more than monohulls, it is possible to estimate their cost based on the information presented in Figure 5.7. DTNSRDC has received information from Mitsui indicating that a SWATH ship might cost 10 percent more than a comparable monohull. If more accurate cost data are desired, it can best be obtained by preparing more detailed designs and seeking the assistance of commercial and Navy cost estimators.

It should be mentioned that steel was not considered in this study because the corrosion allowance drives the minimum scantlings to thicknesses that are generally unacceptable for these small boats.

At the initial SWATH study meeting, it was mentioned that $500,000 per boat (exclusive of MCM equipment) was a target. It appears now that there is an excellent chance that this can be met.

5.6 CONCLUSIONS

The results of this preliminary study are very encouraging. The conceptual designs fall into the desired size range, have good seakeeping characteristics which can be further enhanced by automatic controls, and can be expected to cost less than $500,000 each in production provided commercial practices and standards are used.

Consequently, it is felt that more extensive studies should be conducted to further characterize performance and cost and to allow a look at the possibility of designing a craft that can be disassembled for air transport.

The goal of this effort should be the construction and testing of one or two prototypes in simulated MCM roles. Every effort should be made to establish such a program as soon as possible.

6.

COMPARISON OF SWATH SEAKEEPING WITH MONOHULL

A brief seakeeping comparison was made between the SWATH hull forms proposed by the Task Group; an existing MSL type monohull; and an ASR-type catamaran hull. The data for the monohull was obtained from model tests conducted by the Davidson Laboratory, Stevens Institute of Technology, using an existing hull model similar in proportions to the 36 ft MSL. Due to various constraints, tests were limited to zero speed in head and beam seas. The model was loaded to a scale weight of the existing 36 ft MSL (11 long tons) and these data were then extrapolated to correspond to full scale displacements of the 33 and 54 long ton which correspond to the proposed SWATH designs. The model tests were conducted in regular waves and in a Pierson-Moskowitz sea spectrum. The results are summarized in Table 6.1 which lists the significant and peak values (based on 100 wave encounters) of the amplitudes of heave at the LCG, the pitch angle and the roll angle. Unfortunately, only these three motions were measured in the brief model test.

The corresponding motion characteristics were calculated for the 33- and 54-long-ton SWATH forms using the Davidson Laboratory computer program. These results are also listed in Table 6.1.

The motions of a possible ASR type catamaran hull for 33 and 54 long ton displacements were estimated using response operators taken from model tests reported in References 1 and 2 as defined on Page 11. (See Table 6.1)

The seakeeping advantage of the SWATH configuration over the monohull form is clearly evident. Specifically, the heave and pitch motions for the SWATH are nearly 1/3 to 1/2 of those of the monohull while the roll motions for the SWATH are only 1/3 of those experienced by these other hull forms. At forward speed, with active fin control, it is expected that the motions of the SWATH forms will be reduced even further, again demonstrating their superiority over equivalent monohull and catamaran hull forms.

TABLE 6.1
COMPARISON OF MOTIONS FOR
MCM SWATH, MONOHULL AND ASR CATAMARAN FORMS
(ZERO SPEED)

HULL DESCRIPTION	MONOHULL	MONOHULL	NOSC "A" SWATH	CATAMARAN	MONOHULL	DTNSRDC "B" SWATH	CATAMARAN
Displacement, long ton	8.53	33.0	33.0	33.0	53.0	53.0	53.0
LOA, ft	35.7	56.1	42.0	48.6	65.7	61.5	57.0
Maximum Beam, ft	10.0	15.7	32.1	18.0	18.4	30.3	21.0
LOA/BEAM	3.6	3.6	1.3	2.7	3.6	2.0	2.7
Transverse GM_T, ft	5.7	8.9	1.4	10.0	10.5	3.4	11.7
Natural Roll Period, sec	2.0	2.5	17.6	2.9	2.7	11.7	3.1
Natural Heave Period, sec	2.6	3.3	8.2	5.0	3.5	5.9	5.4
Natural Pitch Period, sec	2.7	3.4	12.1	4.6	3.7	9.5	5.0
SEA STATE							
Sea State Number	2.0	2.5	2.5	2.5	2.8	2.8	2.8
Significant Wave Height, ft	2.2	3.5	3.5	3.5	4.0	4.0	4.0
Modal Period, sec	4.1	5.1	5.1	5.1	5.6	5.6	5.6
HEAD SEA RESULTS							
Significant C.G. Heave (up), ft	1.5	2.4	1.1	1.6	2.7	1.4	1.9
Peak C.G. Heave (up), ft	2.0	3.2	1.7	2.4	3.6	2.1	2.8
Significant Pitch (bow up), deg	5.1	5.1	1.9	8.4	5.1	2.7	8.4
Peak Pitch (bow up), deg	6.6	6.6	2.9	12.5	6.6	4.0	12.5
BEAM SEA RESULTS							
Significant C.G. Heave (up), ft	2.1	3.3	1.0	NA	3.8	1.6	NA
Peak C.G. Heave (up), ft	3.9	6.2	1.5	NA	7.1	2.4	NA
Significant Roll (seaward up), deg	10.1	10.1	4.7	12.1	10.1	5.1	12.1
Peak Roll (seaward up), deg	21.8	21.8	7.0	18.1	21.8	7.6	18.1

NOTES:
1. Monohull form of MSL type. Model test results extrapolated to various size and displacement comparable with SWATH designs.
2. Motion data for SWATH forms calculated using Davidson Laboratory, Stevens Institute of Technology, programs.
3. Pierson-Moskowitz Sea Spectra used in model tests and calculations.
4. Catamaran of ASR type. Model test results extrapolated to various sizes and displacements comparable with SWATH designs. Natural periods derived from peaks of response curves.

APPENDICES

APPENDIX A

STRUCTURAL INTEGRITY OF SWATH SHIPS

There has been concern expressed recently about the structural integrity of SWATH ships in a seaway. This concern is in no small way related to the experiences recorded on the Navy's catamarans, the HAYES and the PIGEON. These ships suffered from design defects which resulted in inadequate cross-structure clearances above the water coupled with excessive ship motions. When these two problems were combined in a seaway, extremely high slam loads were the result. On occasions the cross-structure was damaged by the excessive slam pressures which developed. It should be noted that model test of these catamaran hull forms did reveal the poor motion characteristics and, if instrumented, could have predicted the structure-crushing slam pressures.

There is very little relationship between catamarans and SWATH ships other than the fact that both are twin-hull concepts and both are displacement hull forms. Any attempt to understand the behavior of a SWATH ship by observing the behavior of a catamaran is neither valid nor realistic. SWATH ships are characterized by their small waterplane area which largely decouples these craft from the forces which are generated by passing waves. As a result the motions and accelerations of SWATH ships are significantly less than those characteristics of both monohulls and catamarans.

Scientists and engineers have developed theories which are capable of predicting the loads which SWATH ships will experience at sea. These theories were checked against model test data and full scale data taken from the SSP KAIMALINO. Correlation between the analytic predictions and experimental data is excellent showing that there is good understanding of the physical phenomena involved.

Structural design techniques developed for conventional ships have been modified and adapted to the design of SWATH ships. Again these procedures have been validated against model tests and full scale data from the SSP KAIMALINO. With these validated tools in hand, structural analysts are confident that they can select adequate scantlings to accommodate the loads.

The experiences accumulated to date by the DUPLUS, SSP KAIMALINO and the Japanese ships demonstrate conclusively that properly designed SWATH ships can withstand

the severest of sea conditions without damage. The DUPLUS has operated in the North Sea since 1969. The notoriously severe conditions that can develop in this area do not need elaboration. The DUPLUS has weathered out a three day, 75 yr storm with waves up to 70 ft in height. DUPLUS was the only vessel that remained on station during this storm and she performed useful work immediately afterwards by replacing the broken moor of a tanker.

SSP KAIMALINO has logged over 5000 hr of operations in Hawaiian waters. Here waves of 8-10 ft are common. She has operated in measured waves up to 22 ft high and crew members estimate that they have seen 28-30 ft waves. On one transit between the islands of Oahu and Kauai the SSP encountered 80 kt winds and extremely rough sea conditions. Regular structural inspections have not revealed any structural damage due to seaway induced loads or slamming.

The only SWATH craft which has experienced structural problems is the SUAVE LINO. In this case, design deficiencies resulted in cracks developing along the upper portions of the struts. The naval architect who prepared the plans and specifications for this boat did not have access to the design tools developed by the U.S. Navy. There is also question whether a structural analyst was involved in the design of the SUAVE LINO. Experts have now been consulted and temporary modifications are being installed which are intended to provide adequate structural integrity until time is available to make more extensive and permanent repairs.

In summary, SWATH ships are not catamarans and any attempt to make comparisons between the two must be discounted. Sufficient design techniques have been developed and validated for the prediction of seaway loads and scantlings to provide a high level of confidence in the adequacy of SWATH designs. Experiences with SWATH ships accumulated since 1969 confirm this confidence in the SWATH hull form.

APPENDIX B

SSP KAIMALINO OPERATIONAL EXPERIENCES

The SSP KAIMALINO was designed by NOSC, Hawaii with the assistance of Pearl Harbor Naval Shipyard and the Naval Air Engineering Center as a stable open ocean range support craft for the rough waters around the Hawaiian Islands. Construction took place at the Coast Guard Shipyard, Curtis Bay, Maryland, during the period 1972 through 1974 and the craft arrived in Hawaii in February 1975. Since that time the SSP has logged more than 5000 hr at sea conducting a variety of performance tests, demonstrations and range support operations in sea states up to 6.

The SSP is a small SWATH craft displacing only 225 t and measuring 89 ft length overall by 50 ft beam. She is powered by two 3000 hp GE-T64-6B gas turbines which have been derated to 2250 hp for this marine application. Maximum speed achieved prior to the addition of buoyancy modules was 24 kt. Normal cruise speed on turbines is 12-17 kt. A pair of electro-hydraulic auxiliary propulsion systems provides low speed power and maneuvering capabilities.

The tests and operations of the SSP have been varied and relatively demanding. Characteristics such as speed, maneuvering, seakeeping and structural responses were measured in several sea states and at all directions to the sea. Project support has included participation in submersible vehicle launch and recovery, helicopter certification trials, sonar tests, towed array handling experiments, ship motion simulations, mine countermeasures tests, support for programs at the Barking Sands test range off the island of Kauai and numerous other Navy R&D programs. Such operations have required maneuvering at low, medium and high speeds. These activities have been set against an environmental background ranging from relative calm to high waves (20 ft and above on occasions) and high winds (to 80 kt).

Over this spectrum of operating experiences, the seaworthiness and relative stability under all weather, speed and heading combinations has been found to be exceptional. SSP KAIMALINO maneuvers easily and responds rapidly and precisely to control inputs. From his position at the helm the Craftmaster has full control of the platform within arm's length from startup, throughout maneuver, to shutdown. Visibility ahead is unrestricted and he can observe deck activities aft and communicate conveniently

with the crew. Even inexperienced visitors have maneuvered the SSP with ease. Experienced visiting naval officers have been allowed to dock KAIMALINO and made smooth landings with little or no assistance other than normal verbal instructions from the deck watch to the bridge.

These operational qualities have enabled the SSP to routinely perform many tasks at sea that would have been difficult and in some cases impossible for a monohull. Typically, recovery of objects from the sea is accomplished on the first attempt. On one occasion a wave rider buoy was recovered in a Sea State 5 with 30 kt winds on the first pass even though only one screw was operating and with forward pitch only. The SSP can transit at high speed, go DIW and perform precise stationkeeping, and launch and recover equipment over the side or off the stern or through the center well, even in very adverse sea states.

One of the most dramatic demonstrations involving the SSP was performed for the Naval Sea Systems Command in September 1976 when Dynamic Interface (DI) trials for the SH-2F LAMPS helicopter were conducted with KAIMALINO. The completion of these trials resulted in full daylight certification of the SSP as a LAMPS-capable platform.

During the DI trials, over 80 landings and takeoffs were conducted by the Navy and Coast Guard. The tests were conducted in a variety of sea and wind conditions, including tests up to and including Sea State 4. Most runs were conducted with a 15-kt speed to obtain desired relative winds over the deck and to utilize the Automatic Motion Control System (AMCS); however, a landing was also demonstrated in a Sea State 3 while the SSP was DIW. These tests were conducted with a standard fleet LAMPS helicopter weighing 12,800 lb, and landing crew teams from operational fleet units. The AMCS, as used during the trials, virtually eliminated any motion of the SSP associated with touchdown and takeoff.

Following DI trials, the qualifying pilots expressed several points that are worth noting here. First, the lack of wind turbulence, which is normally associated with conventional ship superstructures, was immediately obvious and aided significantly in the general ease of landings. They suggested it would be of considerable value to maintain such a smooth, structure-free-deck in future air-capable SWATH designs. Second, the minimal motion of the SSP combined with a very favorable wind over the deck resulted in their ability to easily and safely land on the SSP under conditions that would preclude normal landings on the 4,200 t 1052 class LAMPS platforms.

SSP operations are supported entirely on user provided funds and, therefore, the craft must be cost competitive with other available alternatives, both military and commercial. This requires that the boat be highly versatile, low in operating costs and reliable. The SSP has proven its capabilities in each of these areas.

The experiences to date with the SSP suggest that other sizes will provide significant performance improvements in many surface ship missions. In some cases, small SWATH ships may be able to perform missions that currently require much larger monohulls, while larger SWATHS may accomplish missions not possible now. The demonstrated ability to run long straight, relatively precise tracks with greatly reduced motions at low speed, combined with the ability to easily deploy and recover hardware from the platform, indicates that a modest size SWATH ship should make an excellent towed array platform or oceanographic ship. Certainly, larger versions are expected to be ideal air-capable platforms, or may lend themselves to multiple-mission roles with modular components easily added or removed.

As a laboratory support platform, the SSP KAIMALINO has exceeded expectations; as a first-of-a-kind SWATH ship her performance has been exceptionally valuable. Hopefully, the SSP KAIMALINO will be the forerunner of a new kind of surface platform that offers greatly improved performance with smaller, less expensive ships.

APPENDIX C

SUMMARY OF CURRENT SWATH DEVELOPMENT EFFORTS

UNITED STATES

- RMI and L. Friedman, owner of the 40 t SUAVE LINO, have formed SWATH Enterprises, Inc. to exploit commercial applications for SWATH craft of similar size: SUAVE LINO is capable of 18 kt.

- The naval oceanographic community, the Coast Guard & the Army Corps of Engineers are in the process of conducting operational evaluations of SUAVE LINO.

- JGMA, a company based in Houston, is actively exploring SWATH applications for the offshore oil industry. Their current focus is on a ship of 2500 t.

- The Coast Guard has funded a study of SWATH potential for projected classes of cutters.

JAPAN

- Mitsui Engineering & Shipbuilding Co. has had an active SWATH research and development program since 1970.

- Mitsui has, to date, built three SWATH craft:

  - 18 t experimental craft MARINE ACE

  - 240 t, 20-kt coastal survey vessel KOTOZAKI

  - 350 t, 24-kt, aluminum ferry SEAGULL capable of carrying a 747 plane load of passengers.

- Mitsui has completed a design for a 2800 t oceanographic research ship, and expects to be launched in 1984.

- Mitsubishi Heavy Industries has built a 250 t, 20-kt hydrographic survey vessel for the Inland Sea.

CANADA

- o Beginning in 1979, the Canadian Navy has twice arranged for one of their maritime engineering officers to be assigned to DTNSRDC for a tour of 2 years, so that he could bring back to Canada an understanding of SWATH design technology.

- o In 1979 the Canadian Navy began to create an in-house capability in SWATH hydrodynamics and structural design.

- o Since 1980 the Canadian Navy has had a joint SWATH technology development program with the Royal Netherlands Navy. The United States and the United Kingdom participate in this effort as invited observers.

- o As part of its future surface ship study, the Canadian Navy is producing feasibility designs of a 5000 t SWATH combatant carrying four helicopters and a 7800 t combatant carring six helicopters.

- o The Canadian Navy may consider a SWATH of about 500 t as part of its minor war vessel program.

UNITED KINGDOM

- o In 1981 the Admiralty Marine Technology Establishment, Haslar initiated a cooperative program of SWATH hydrodynamics research with DTNSRDC.

- o In November 1981 the Ministry of Defense appointed a naval constructor to DTNSRDC for a tour of two to three years, principally to monitor SWATH development efforts in the United States and to become familiar with SWATH design technology.

- o Possible future applications for SWATH are seen as Coastal MCM, Fisheries Protection and an ASW Corvette.

- o Vosper, International has developed a design for a 900 t offshore patrol vessel with a speed of 21.5 kt and capable of carrying one Lynx helicopter.

NETHERLANDS

- o In 1968 the Netherlands Offshore Co. built the 1430 t DUPLUS, a SWATH-like workboat that has been operating since then in the North Sea.

- The Royal Netherlands Navy has embarked on a joint technology development effort with Canada to support feasibility design studies of a four-helicopter combatant for possible acquisition in 1987.

SPAIN

- The Spanish Navy has requested that a joint information exchange program in SWATH technology be established.
- In 1981 the Spanish Navy formed a study team with a three-year charter to develop a SWATH patrol craft design of about 800 t displacement with a top speed of 30 kt.

NORWAY

- Aker Engineering A/S has developed a SWATH design of about 1500 t to service offshore oil platforms in the North Sea. The design has a capacity of 400 passengers and a speed of 26 kt.

FINLAND

- Wartsila has developed a SWATH design for a 1500-passenger ocean liner, with a length of 163 m, and a cruising speed of 16 kt.